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1 **The distribution of ^{137}Cs, K, Rb and Cs in plants in a *Sphagnum*-dominated**
2 **peatland in eastern central Sweden**
3
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16
17 **Abstract**
18 We record the distribution of ^{137}Cs, K, Rb and Cs within individual *Sphagnum* plants
19 (down to 20 cm depth) as well as ^{137}Cs in vascular plants growing on a peatland in
20 eastern central Sweden. In *Calluna vulgaris* ^{137}Cs was mainly located within the green
21 parts, whereas *Andromeda polifolia*, *Eriophorum vaginatum* and *Vaccinium oxycoccos*
22 showed higher ^{137}Cs activity in roots. *Carex rostrata* and *Menyanthes trifoliata* showed
23 variable distribution of ^{137}Cs within the plants. The patterns of ^{137}Cs activity
24 concentration distribution as well as K, Rb and Cs concentrations within individual
25 *Sphagnum* plants were rather similar and were usually highest in the capitula and/or in
26 the subapical segments and lowest in the lower dead segments, which suggests
27 continuous relocation of those elements to the actively growing apical part. The ^{137}Cs and
28 K showed relatively weak correlations, especially in capitula and living green segments
29 (0-10 cm) of the plant (r = 0.50). The strongest correlations were revealed between ^{137}Cs
30 and Rb (r = 0.89), and between ^{137}Cs and stable Cs (r = 0.84). This suggests similarities
31 between ^{137}Cs and Rb in uptake and relocation within the *Sphagnum*, but that ^{137}Cs
32 differs from K.
33
34
35 *Keywords*: fen, *Sphagnum*, uptake, vascular plant
36
37 **1. Introduction**
38
39   Peatlands are areas where remains of plant litter have accumulated under water-
40 logging as a result of anoxic conditions and low decomposability of the plant material.
41 They are generally nutrient-poor habitats. This holds in particular for the northern
42 hemisphere temperate and boreal bogs, in which peat formation has built up a dome
43 isolating the vegetation from the surrounding groundwater. Hence bogs are ombrotrophic,
44 i.e., all water and nutrient supply to the vegetation is from aerial dust and precipitation,
45 resulting in an extremely nutrient-poor ecosystem often formed and dominated by peat
46 mosses (*Sphagnum*). *Sphagnum*-dominated peatlands with some groundwater inflow (i.e.

weakly minerotrophic 'poor fens') are almost as nutrient poor and acid as true bogs. *Sphagnum* plants absorb and retain substantial amount of fallout-derived radiocaesium (Hanson, 1982; Nifontova, 2005). Recently, some attention has been given to the transfer of the radioactive caesium isotope ^{137}Cs within raised bogs (Bunzl and Kracke, 1989; Rosén et al., 2009). Relatively high ^{137}Cs bioavailability to bog vegetation and mosses in particular has been shown (Bunzl and Kracke, 1989; Orlov et al., 1999). The transfer of ^{137}Cs within a peatland ecosystem is different from that in forest or on agricultural land. In soils with high clay content, there is low bioavailability and low vertical migration rate of radiocaesium due to its binding to some clay minerals (Cornell, 1993; Wauters et al., 1996; Rosén et al., 1999). In nutrient-poor but organic-matter-rich forest soils, the vertical migration rate of ^{137}Cs is also low but the bioavailability is often high, particularly for mycorrhizal fungi (Olsen et al., 1990; Vinichuk and Johansson, 2003; Vinichuk et al., 2004). In forests and pastures, extensive fungal mycelium counteracts the downward transport of ^{137}Cs by an upward translocation flux (Rafferty et al., 1997, 2000). This results in very slow net downward transport of ^{137}Cs in the soil profile.

It appears that ^{137}Cs moves in the peat through advection in the peat water (review by Turetsky et al., 2004). Small amounts of clay mineral in the peat will reduce Cs mobility (MacKenzie et al., 1997), but most *Sphagnum* peat is virtually completely organic matter. In wet parts of open peatlands that lack fungal mycelium, the downward migration of ^{137}Cs in the *Sphagnum* layers is expected to be faster than in forest soil. Recent studies (Schleich et al., 2000; Rosén et al., 2009) show that Cs is translocated continuously towards to growing apex of the *Sphagnum* shoots, where it is accumulated. Some attempts have been made to investigate whether ^{137}C is associated with essential biomacromolecules in mosses and to determine the ^{137}Cs distribution among intracellular moss compartments (Dragović et al., 2004).

The chemical behaviour of radiocaesium could be expected to be similar to that of stable Cs and other alkali metals, K, Rb, which have rather similar physicochemical properties. Stable Cs usually provides a useful analogy for observing long-term variation and transfer parameters of ^{137}Cs in a specific environment, particularly in peatlands that are cut of from input of Cs from the mineral soil. Chao et al. (2008) have found that as a whole, ^{137}Cs is positively associated with K concentration across plant species in an undisturbed forest ecosystem, which suggests that the ^{137}Cs, stable Cs and K are assimilated in a similar way, and that the elements pass through the biological cycle together. The Cs influx into cells and its use of K transporters is discussed in the review by White and Broadley (2000). However, the relationships between Cs and K are not completely understood, since Cs does not always show high correlations with K (Yamagata et al., 1959) and it has been suggested that there is an alternative pathway for Cs uptake into fungal cells (Yoshida and Muramatsu, 1998). The relationship between K and Rb is not well understood (Yoshida and Muramatsu, 1998), and it is not clear whether Cs follows the same pathways as K for *Sphagnum*. Virtually no studies have been conducted to clarify the influence of alkali metals (Cs, Rb) on ^{137}Cs distribution and cycling processes in nutrient-poor peatlands. Such information is needed to accurately interpret the processes that determine caesium uptake and binding. Plant species growing on peat have - to a varying degree - the capacity to influence uptake and binding of the radionuclides but no systematic study has been carried out involving all the dominant species of *Sphagnum* peatlands and comprehending both competitions for radionuclides

93   and for nutrients. The important role of *Sphagnum* mosses in mineral nutrient turnover in
94   nutrient-poor ecosystems, in particular their role in ^{137}Cs uptake and binding necessitates
95   a clear understanding of the mechanisms involved.
96   The main aim of the present study was to compare the distribution of ^{137}Cs, K, Rb and
97   Cs in the uppermost capitulum and subapical segments of *Sphagnum* mosses to be able to
98   discuss the possible mechanisms involved in radiocaesium uptake and retention within
99   *Sphagnum* plants. Furthermore, we also aimed to quantify ^{137}Cs in the dominant vascular
100 plants associated with *Sphagnum* and its distribution within these plants.
101
102 **2. Materials and methods**
103 *2.1. Study area*
104
105   The study area was a small peatland (Pålsjömossen) within a coniferous forest in
106 eastern central Sweden, about 35 km NW of Uppsala (60°03′40″ N, 17°07′47″ E).
107 Ground deposition of ^{137}Cs in 2005 was 23 000 Bq m^{-2} (Rosén et al., 2009). The sampled
108 part of the peatland was open and *Sphagnum*-dominated. A weak minerotrophic influence
109 was indicated by the dominance of *S. papillosum*, and the presence of *Carex rostrata*, *C.
110 pauciflora* and *Menyanthes trifoliata* (fen indicators in the region; Rydin et al., 1999).
111 The area had scattered hummocks mostly built by *S. fuscum*, and dominated by dwarf-
112 shrubs such as *Andromeda polifolia, Calluna vulgaris*, *Empetrum nigrum* and *Vaccinium
113 oxycoccos*. Sampling was made within a 25-m^2 low, flat 'lawn community' (Rydin and
114 Jeglum 2006) with the water table most of the time less than 15 cm below the surface.
115 These parts were totally covered by *S. papillosum*, *S. angustifolium* and *S. magellanicum*
116 with an abundant cover of *Eriophorum vaginatum*. Sparsely occurring were *Andromeda
117 polifolia, Carex rostrata*, *Drosera rotundifolia*, *Menynthes trifoliata* and *Vaccinium
118 oxycoccos*. The surface water pH was 3.9-4.4 (June 2009).
119
120 *2.2. Sampling and treatment*
121 *2.2.1. Vascular plants*
122
123   Sixty three composite vascular plant samples were collected from the end of July to
124 the middle of September 2008. The samples were divided into active green tissue,
125 supportive tissue, and roots (in some species fine roots; < 2 mm in diameter). Some
126 species were further divided into finer sections (see Table 1). For *Drosera* the whole
127 plant was analyzed.
128   The samples were carefully cleaned of any extraneous fragments, and dried at 40°C to
129 constant weight. They were then milled to 2 mm or cut into fragments of a few mm to
130 achieve homogeneous and well-mixed samples that were analysed for activity
131 concentration of ^{137}Cs.
132
133 *2.2.2. Sphagnum mosses*
134
135   Samples of individual *Sphagnum* shoots that held together down to 20 cm were
136 randomly collected in 2007 (May and September) and 2008 (July, August and
137 September). All together 13 samples of *Sphagnum* plants were collected and analysed;
138 three in 2007 and ten sets in 2008. Each sample consisted of approx. of 20-60 individual

139   *Sphagnum* plants (mostly *S. papillosum*, in a few cases *S. angustifolium* or *S.*
140   *magellanicum*). In the laboratory fresh individual erect and tightly interwoven *Sphagnum*
141   plants were sectioned into 1 cm (0-10) or 2 cm (10-20 cm) long segments down to 20 cm
142   from the growing apex. The ^{137}Cs activity concentrations were measured in fresh
143   *Sphagnum* segments. Thereafter the samples were dried at 40°C to constant weight and
144   analysed for K, Rb, and Cs.

145

146   *2.3. Measurements and data treatment*

147

148   The activity concentration (Bq kg^{-1}) of ^{137}Cs in plant samples was determined using
149   well-calibrated HPGe detectors. Plant material was measured in different geometries
150   filled up, except a few fine root samples, which contained about 1 g of dry material. The
151   measuring time was chosen in order to obtain a statistical error due to the random process
152   of decays ranging between 5 and 10%. All ^{137}Cs activity concentrations were recalculated
153   to the sampling date and expressed on a dry mass basis. Analysis of *Sphagnum* segments
154   for K, Rb and Cs was done after digestion with nitric acid and hydrogen fluoride by a
155   combination of ICP-AES and ICP-SFMS techniques by ALS Scandinavia AB. For K
156   concentration determination ICP-AES and for Cs and Rb ICP-SFMS was used giving
157   detection limits 200, 0.04, and 0.008 μg kg^{-1}, respectively. Differences in ^{137}Cs activity
158   concentration among species and among plant parts within species were tested by
159   ANOVA followed by Tukey pairwise comparisons using Minitab ver. 15 (Minitab Inc.,
160   2006).

161

162   **3. Results**
163   *3.1. ^{137}Cs activity concentration in vascular plants*

164

165   Table 1 shows the ^{137}Cs activity concentration in the plant parts sampled. Comparing
166   the green parts among species, *Calluna vulgaris* had a significantly higher ^{137}Cs activity
167   concentration than the other species (ANOVA: $F_{5, 12} = 10.59$; $P < 0.001$), but there were
168   no significant differences among species in the root fraction.
169   When different plant parts were compared within species, the general pattern was that
170   brown, senescent parts had low, and roots had high activity concentration. Statistically
171   significant differences were found in *Calluna vulgaris* where the activity concentration
172   was higher in the green parts than in the woody parts ($F_{2, 4} = 9.35$; $P = 0.031$), and in
173   *Eriophorum vaginatum* where the activity concentration was higher in the roots than in
174   the green leaves ($F_{2, 9} = 6.98$; $P = 0.015$). *Drosera rotundifolia* was analysed as a whole
175   plant and had intermediate ^{137}Cs activity concentration. Disregarding the brown,
176   senescent parts, the variation among plant parts was particularly small in *Eriophorum*
177   *vaginatum* and *Menyanthes trifoliata* (Table 1).

178

179

180   **Table 1**
181   Activity concentration of ^{137}Cs (kBq kg^{-1}) in various plants organs. Fine roots were
182   defined as < 2 mm in diameter.

183

| Plant species	n	Mean (range)
Andromeda polifolia green shoots (mainly leaves)	3	1.1 (0.85-1.4)
A. polifolia woody parts (above and belowground stems and coarse roots)	3	1.0 (0.88-1.3)
A. polifolia fine roots	3	3.1 (2.7-4.6)
Calluna vulgaris green shoots (mainly leaves)	3	12.8 (9.3-17.1)
C. vulgaris woody parts (above and belowground stems and coarse roots)	2	2.1 (2.0-2.1)
C. vulgaris fine roots	2	5.7 (5.1-6.3)
Carex rostrata infructescence (ripe female spikes)	2	3.7 (2.8-4.6)
C. rostrata green leaves	4	4.4 (1.9-10.6)
C. rostrata brown, senescent leaves	4	1.8 (1.2-3.1)
C. rostrata roots	2	6.2 (1.9-10.6)
Drosera rotundifolia	2	4.7 (4.0-5.5)
Eriophorum vaginatum green leaves	4	2.0 (1.3-3.3)
E. vaginatum brown, senescent leaves	5	1.8 (1.2-3.4)
E. vaginatum roots	3	7.3 (3.2-11.8)
Menyanthes trifoliata green parts (shoots and leaves)	4	2.6 (2.5-3.0)
M. trifoliata stems and rhizomes	5	1.6 (1.3-2.3)
M. trifoliata roots	3	2.3 (1.6-3.3)
Vaccinium oxycoccos green shoots (mainly leaves)	3	1.5 (1.1-1.7)
V. oxycoccos woody parts (above and belowground stems and coarse roots)	3	1.6 (1.5-1.9)
V. oxycoccos fine roots	3	3.2 (2.2-3.3)

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185
186   *3.2. ^{137}Cs activity concentration in Sphagnum*
187
188   In Fig. 1 averaged ^{137}Cs activity concentrations in *Sphagnum* segments are presented.
189   Summarized data show that within the upper 10 cm from the capitulum ^{137}Cs activity
190   concentration in *Sphagnum* plants was about 3 350 Bq kg^{-1} with relatively small
191   variations. Below 10-12 cm the activity gradually declines with depth and in the lowest
192   segments of *Sphagnum* ^{137}Cs activity concentrations was about 1 370 Bq kg^{-1}.
193

Activity concentration of ^{137}Cs, kBq kg^{-1}
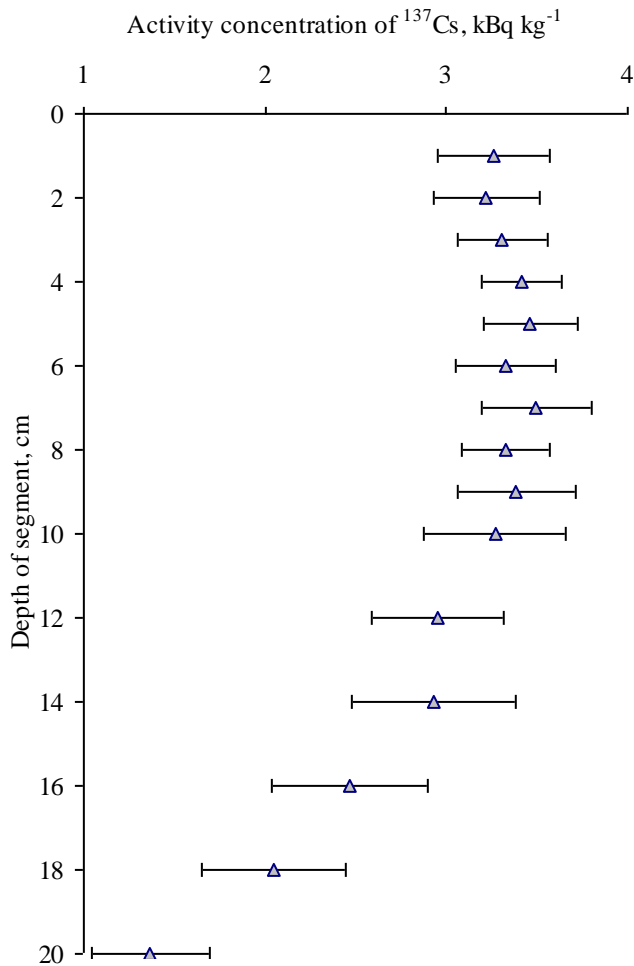
194

195

196

197 **Fig. 1.** Average ^{137}Cs activity concentration (Bq kg^{-1}) in *Sphagnum* segments (+/- SE, n =
198 13).

199

200

201 *3.3. Potassium, rubidium and caesium concentrations in Sphagnum*

202

203 Averaged concentrations of K, Rb and Cs in *Sphagnum* segments are shown in Figure
204 2. For individual samples potassium concentrations ranged between 508 and 4 970 mg
205 kg^{-1} (mean 3 096); rubidium between 2.4 and 31.4 mg kg^{-1} (mean 18.9) and Cs between
206 0.046 and 0.363 mg kg^{-1} (mean 0.204). Concentrations of Rb and Cs were rather constant
207 in the upper 0-10 cm segments of *Sphagnum* moss and gradually declined in the lower
208 parts of the plant length, whereas the concentration of K decreased with increasing depth
209 below 5 cm. Generally, the distributions of all three alkali metal were quite similar to that
210 found for ^{137}Cs, but with a somewhat weaker increase towards the surface for Rb. The
211 ^{137}Cs activity concentrations showed the highest coefficient of variation (standard

6

212 deviation divided by the mean) in *Sphagnum* (43%). The coefficient of variation for K,
213 Rb and Cs concentrations was 35%, 35% and 37%, respectively.
214
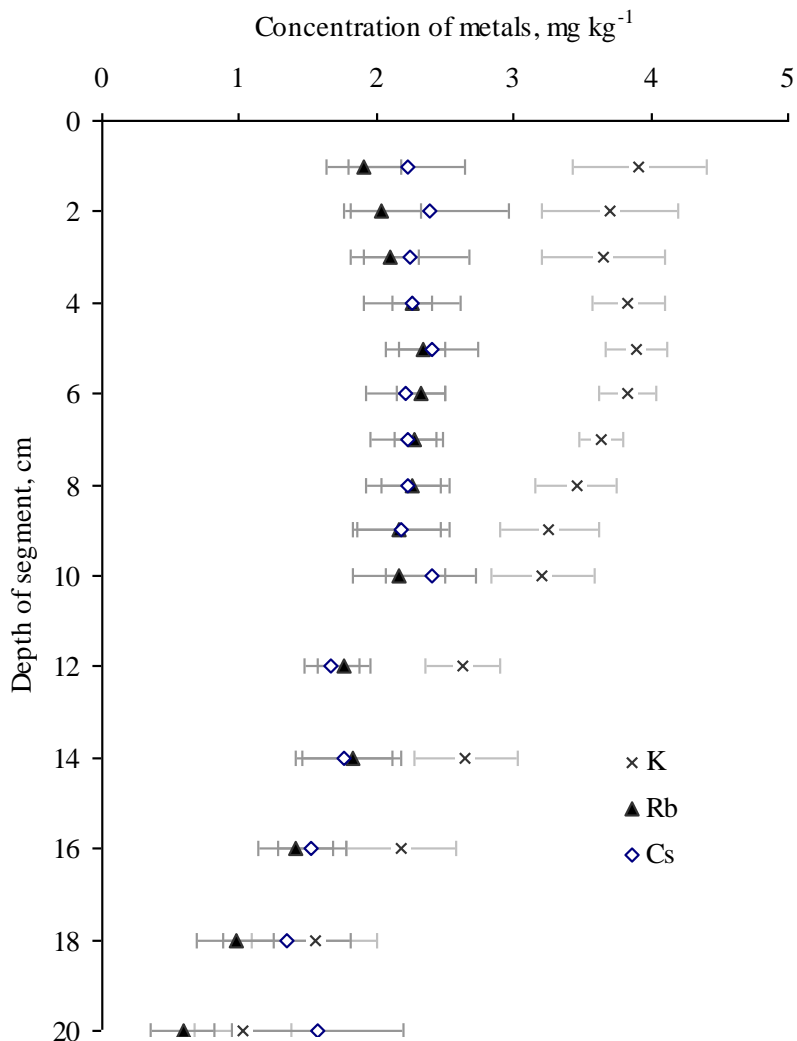
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216

217 **Fig. 2.** Average concentrations of K (scale values should be multiplied by 10^3), Rb $(x10^1)$
218 and Cs $(x10^{-1})$ (mg kg^{-1}) in *Sphagnum* segments (+/- SE, n = 4).
219
220   Ratios between concentrations of all three alkali metals and ^{137}Cs activity
221 concentrations i.e. Cs/^{137}Cs; K/^{137}Cs and Rb/^{137}Cs were fairly constant through the upper
222 part (0-16 cm) of *Sphagnum* plants (Fig. 3). The ratio K/Rb was somewhat higher in
223 uppermost (0-2 cm) and lowest (18-20 cm) parts (Fig. 3).
224
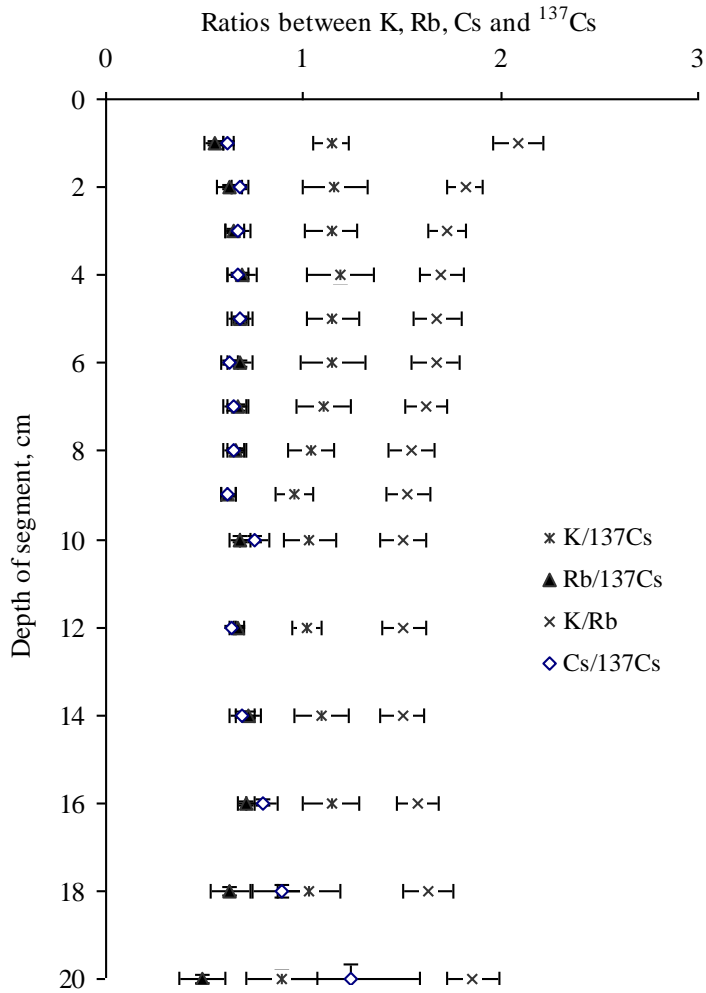
Fig. 3. Ratios between K/^{137}Cs, Rb/^{137}Cs (scale values should be multiplied by 10^{-2}), K/Rb (x10^2) and Cs/^{137}Cs (x10^{-4}) in *Sphagnum* segments. Calculations based on concentrations in mg kg^{-1} for stable isotopes and Bq kg^{-1} for ^{137}Cs (+/- SE, n = 13 for ^{137}Cs; n = 4 for each of K, Rb and Cs).

There were close positive correlations between K, Rb and Cs concentrations and ^{137}Cs activity concentrations in *Sphagnum* segments (Fig. 4.). Correlation between ^{137}Cs activity concentrations and Rb concentrations was highest (r = 0.95; p <0.001) in 10-20 cm length of *Sphagnum* plants, while ^{137}Cs and K showed a weaker correlation when only the upper 0-10 cm part of *Sphagnum* plants were analysed (r = 0.50; p <0.001).
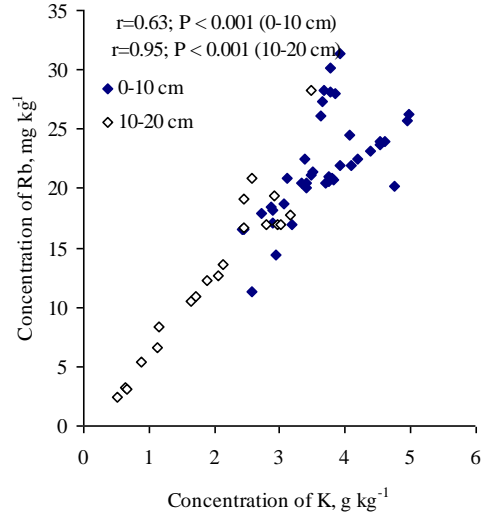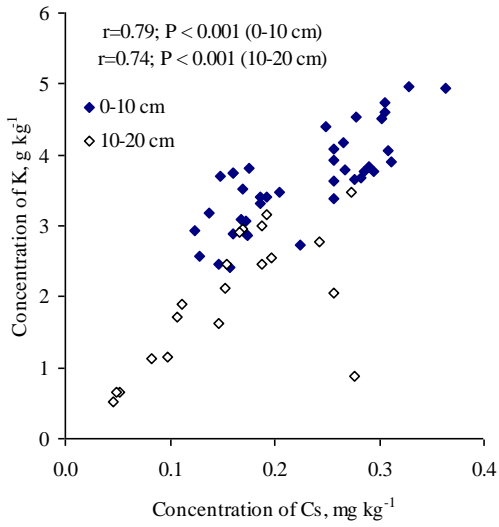
238
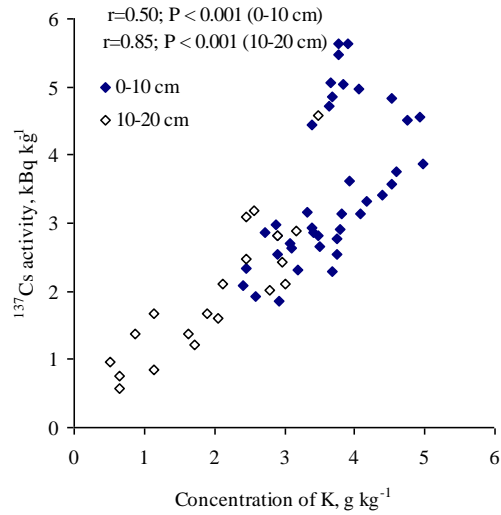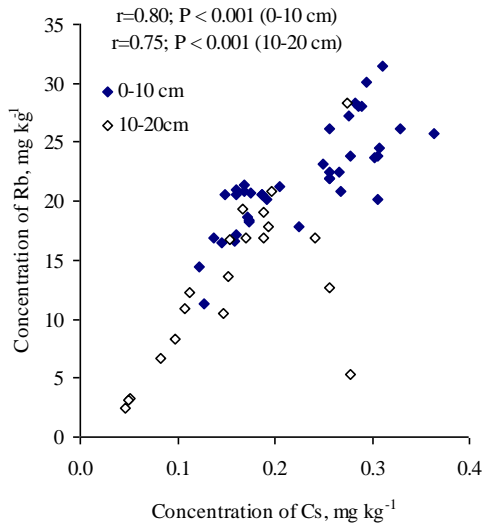
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240

241 **Fig. 4.** Relationships between K, Rb, Cs and ^{137}Cs concentrations in *Sphagnum* segments.
242
243
244 **4. Discussion**
245
246   Two important features should be pointed out when discussing distributions of K, Rb,
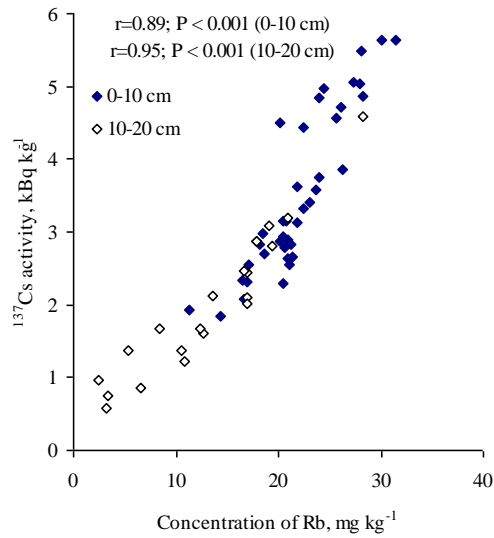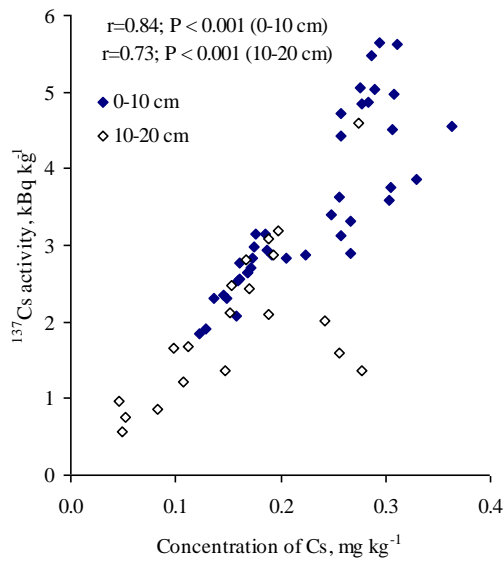247 Cs and ^{137}Cs in a *Sphagnum*-dominated peatland. Firstly, this type of peatland is an
248 extremely nutrient-poor, where only a few plant and fungal species, which produce small
249 fruit bodies can grow and no mycorrhiza except ericoid mycorrhiza exists. Secondly, the
250 upper part of the stratigraphy is composed of living *Sphagnum* cells which selectively
251 absorb mineral ions from the surrounding water, and binding of such ions can be at
252 exchange sites outside the cell or inside the cell for Cs, K and Rb.
253
254   *4.1. Vascular plants*
255
256 The results show a strong tendency of ^{137}Cs being relocated by biological processes
257 within vascular plants into actively growing leaves and fine roots. There are some
258 differences in ^{137}Cs concentration and location among species, but the mechanisms
259 behind the differences are difficult to establish. Intuitively, one can envisage that the
260 lateral root distribution of *Calluna vulgaris*, mostly within the top 10 cm of *Sphagnum*
261 (Heath et al., 1938; Messier and Kimmins, 1991) and its active ericoid mycorrhiza should
262 be reasons for its high ^{137}Cs activity concentration. However, *Andromeda polifolia* also
263 has a large below-ground compartment (up to 98% of its biomass; Wallén, 1986) with
264 ericoid mycorrhiza and a root system which is even shallower than that of *Calluna*
265 (Metsävainio, 1931). Both species are rooted within the zone with highest ^{137}Cs activity
266 concentration in the *Sphagnum* substrate. It is therefore somewhat surprising that *Calluna*
267 has considerably higher, and *Andromeda* somewhat lower ^{137}Cs activity concentration
268 than the *Sphagnum* in which they are rooted. The third ericoid species, *Vaccinium*
269 *ocycoccos*, has a shallow but rather extensive root system hardly penetrating only a few
270 cm into the living parts of the moss layer (Malmer at al. 1994) with ericoid mycorrhiza
271 (Harley and Harley, 1987) has ^{137}Cs levels similar to *Andromeda*.
272
273 Studies on *Calluna* by Strandberg and Johansson (1999) showed that the presence of
274 mycorrhiza increased the total amounts of K in the plants, but it also promoted biomass
275 growth with the end result that the K concentration was similar in mycorrhizal and non-
276 mycorrhizal plants. Since K and radiocaesium are generally strongly coupled in their
277 behaviour (e.g., Bunzl and Kracke, 1989) it is not likely that mycorrhizal activity is the
278 reason for the high ^{137}Cs activity concentration in *Calluna*. A difference between the
279 ericoid species is that it is more difficult to separate the current year's shoots from older
280 ones in *Calluna* than in *Andromeda*, so our *Calluna* samples probably contained more old
281 material than the *Andromeda* samples. However, this is probably also not the reason for
282 the high levels of ^{137}Cs, since Malmer and Wallén (1986) showed that the K
283 concentration decreases with shoot age in *Andromeda* as well as in *Empetrum*
284 *hermaphroditum* (another ericoid dwarf-shrub with similar growth form to *Calluna*).
285 Instead it indicates that *Calluna* is very efficient in retaining radiocaesium in its green
286 tissue.

287

288   In 1989, three years after the Chernobyl fallout, *Calluna*, *Vaccinium* and *Drosera* had
289   very high ^{137}Cs activity concentrations (43.5, 14.7 and 25.0 kBq kg^{-1}, respectively) at
290   Pålsjömossen, probably as a result of the immediate uptake in the superficial root system.
291   Even if it has decreased strongly since then (Rosén et al., 2009), *Calluna* is the species
292   with the most long-lived above-ground structures, making it understandable that it has
293   retained high level of radiocaesium. Both *Andromeda* and *Vaccinium*, and especially the
294   other investigated species (*Menyanthes*, *Carex*, *Eriophorum*) have a quicker turnover of
295   above-ground material. Even if the activity concentration in their senescent leaves is
296   rather low, radiocaesium is gradually lost by the annual shedding of leaves. Instead these
297   deep-rooted species (Sjörs, 1991) accumulate ^{137}Cs in their active roots. This is most
298   obvious in *Eriophorum vaginatum* which is renowned for its ability to recycle nutrients
299   internally (Cholewa and Griffith, 2004).

300

301   The root system of the insectivorous, short-lived perennial plant *Drosera rotundifolia* is
302   very shallow - less than 6 cm (Crowder et al., 1990), and it has a ^{137}Cs activity
303   concentrations similar to that of near-surface *Sphagnum*.
304   *4.2. Sphagnum mosses*

305

306   The distribution of ^{137}Cs within *Sphagnum* plant was found to be rather similar to
307   stable K, Rb and Cs. The ^{137}Cs activity concentrations as well as K, Rb and Cs
308   concentrations were always highest in the uppermost 0-10 cm segments of *Sphagnum* (in
309   the capitula and the subapical segments) and gradually decreased in older parts of plant.
310   Such distribution can be interpreted as dependent on the living cells of capitula and living
311   green segments in the upper part of *Sphagnum*. Similar patterns of K distribution within
312   *Sphagnum* plants were reported in other studies (Malmer, 1988; Wojtuń, 1994; Hájek,
313   2008). Obviously, ^{137}Cs is taken up and relocated by *Sphagnum* plants in similar ways as
314   stable alkali metals studied, since the ratios between K, Rb, Cs and ^{137}Cs in *Sphagnum*
315   segments (Fig. 3) were much the same down to about 16 cm and displayed slightly
316   different pattern in lower part of the plant.
317   The marked decrease in the ^{137}Cs activity concentration below 14 cm (Fig. 1) raises
318   the question: At what depth was the 1986 Chernobyl horizon when the sampling was
319   made? A peat core was sampled in May 2003 at Åkerlänna Römosse, an open bog 14 km
320   SW of Pålsjömossen by van der Linden et al. (2008). Detailed dating by ^{14}C wiggle-
321   matching indicated that the Chernobyl horizon was then at 17 cm depth. Depth-age data
322   showed a linear annual peat increment of 1.3 cm yr^{-1} over the last decade ($R^2 = 0.998$),
323   indicating that the Chernobyl horizon would be at about 23 cm depth when our ^{137}Cs
324   sampling was made in 2007-08. Even if there are uncertainties when applying data from a
325   different peatland, the Chernobyl horizon should be at, or below, the lowest segments
326   sampled. An upward migration of ^{137}Cs seems obvious, but any downward migration
327   cannot be tested in this study. An upward migration of ^{137}Cs has also been observed in
328   earlier studies (Rosén et al., 2009). Similarly, most of the ^{137}Cs from the nuclear bomb
329   tests from 1963 was retained in the top few cm of *Sphagnum* peat 20 years later, but there
330   was also a lower peak that seemed to be at the level where the 1963 peat was laid down
331   (Clymo, 1983). Also *Cladonia* lichens retain high activity concentrations in the shoot
332   apices (Mattsson, 1972).

Presumably, ^{137}Cs is binding within capitula, living green segments and dead brown segments of *Sphagnum* plant. According to Gstoettner and Fisher (1997) the uptake of some metals (Cd, Cr, and Zn) in *Sphagnum papillosum* is a passive process since they found that living and dead moss accumulated metal equally. For a wide range of bryophytes, Dragović et al. (2004) found that ^{137}Cs was primarily bound by cation exchange, with only a few percent occurring in biomolecules. *Sphagnum* mosses are known to have remarkably high cation exchange capacity (Clymo, 1963). According to Russell (1988) a high surface activity of *Sphagnum* related to its high cation exchange capacity, which ranges between 90-140 meq/100 g. Porter and Orr (1975) showed that in a water saturated peat moss layer water washes (1 L de-ionised water added to a column of about 1.4 L volume) removed a total of about 60 % of K from *Sphagnum*, indicating that this element was held on cation exchange sites. In turn the desiccation of the living moss usually causes cation leakage from cell cytoplasm during which most of the effused K^+ is retained on the exchange sites and reutilized during the recovery after rewetting (Brown and Brümelis, 1996; Bates 1997). However, this is not necessarily so for ^{137}Cs, since ^{137}Cs showed a weaker correlation with K, especially in the uppermost part of the plant, which means that ^{137}Cs uptake might be somewhat different from that of K. Besides, ^{137}Cs activity concentrations even within the same segments of the plant showed higher variation compared to K concentration. An even stronger decoupling between ^{137}Cs and K was observed in the forest moss *Pleurozium schreberi* in which ^{137}Cs was retained to a higher degree in senescent parts (Mattsson and Lidén, 1975). Rather close correlations, however, were found between Rb and ^{137}Cs, which might suggest similarities in their uptake and relocation. These observations fit rather well with data obtained by Yoshida and Muramatsu (1998) for fungi.

Some of the lower parts of *Sphagnum* plants are still alive and able to create a new shoot (Clymo and Duckett, 1986; Högström, 1997), however, much of lower stem is dead though still connected to the capitulum. Thus, the decrease of ^{137}Cs activity concentration in plant segments below 10 cm indicates a release of the radionuclide from dying-off lower part of *Sphagnum* and internal translocation to the capitulum. The mechanism of radiocaesium and alkali metals relocation within *Sphagnum* is most likely the same active translocation as described for metabolites by Rydin and Clymo (1989). The recently suggested external buoyancy-driven transport (Rappoldt et al., 2003) could redistribute ^{137}Cs, but since field evidence suggested that buoyancy led to a downward migration of K (Adema et al., 2006) this mechanism seems unlikely. Likewise, a passive downwash and upwash (see Clymo and Mackay, 1987) cannot explain the accumulation towards the surface.

5. Conclusions

Rooting depth and an active mycorrhiza seems to be the main factors affecting ^{137}Cs activity in vascular plants on peatlands. Relatively shallow root systems of vascular plants favour ^{137}Cs uptake from the zone where the concentration is high in the *Sphagnum* and result in fast decline of activity with time. The ^{137}Cs activity in plants with more deeply located roots was lower and did not change with time.

For *Sphagnum* the distribution of ^{137}Cs can be driven by several processes: (1) Cation exchange is important and gives similar patterns in all the studied monovalent cations; (2)

uptake/retention in living cells; and (3) downwash and upwash by water outside the plants. It appears that the most important mechanism is (4) internal translocation to active tissue and the apex, which can explain the accumulation in the top layer of the mosses, and which can also explain the accumulation in green parts and fine roots in vascular plants.

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