CORSO DI BOTANICA SISTEMATICA

## **LEZIONE 52**

Radiocontaminazione di funghi, piante vascolari e muschi dopo l'incidente di Chernobyl



#### LA CONTAMINAZIONE DA CESIO-134 E CESIO-137 NEI MACROMICETI DEL FRIULI-VENEZIA GIULIA NEL 1986

#### P.L. NIMIS, C. GIOVANI, R. PADOVANI \*

Keywords: Chernobyl, Fungi, Radioactivity, Friuli-Venezia Giulia.

**Abstract:** This study is based on the measure of the <sup>134</sup> Cs and <sup>137</sup> Cs content in 298 samples belonging to 120 species of macromicetes, collected in 37 stations throughout the Friuli-Venezia Giulia Region (north eastern Italy) in September-October 1986. Significant differences in contamination have been recorded both among species collected in the same station, and among average values of the stations themselves. The differences among species of the same stations seem to depend on the depth of the mycelium in the soil: contamination is highest in the fungi with superficial mycelium, lowest in those that are in symbiosis with deep-rooting deciduous trees. This is related to the fact that most of the radionuclides are presently concentrated in the upper horizon of the forest soil, as demonstrated by the analysis of 59 soil samples collected in the 37 stations. The differences among stations are well correlated to the amount of precipitation in the days following the Chernobyl disaster. This allowed the elaboration of a contamination map of the Friuli-Venezia Giulia Region based on precipitation and contamination data: the most polluted areas are located in the Carnian and Julian Pre-Alps, whereas the lowland has been but little affected by radioactive deposition. The average ratio <sup>137</sup> Cs deriving from nuclear tests.

#### **RADIOCESIUM IN PLANTS OF FOREST ECOSYSTEMS**

#### Pier Luigi NIMIS

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Keywords: Forests, Radiocesium, Radioecology, Vegetation.

Abstract: This paper presents a review of the behaviour of radiocesium in plants of forest ecosystems, based on a screening of 375 articles. Particular stress is given to those factors which affect data variability in plants, such as vertical and horizontal patterns of radioactivity in soils due to interception, resuspension, wash-off, litter fall etc. The behaviour of radiocesium in different horizons of forest soils is discussed. The paper summarizes the main uptake mechanisms in fungi, lichens, bryophytes and higher plants, and the possible use of these organisms as bioaccumulators of radioactive deposition. For higher plants, the effects of several factors on root uptake are considered, such as pH, organic matter and clay content of different soil horizons, the concentrations of other ions in the soil solution, rooting depths, mycorrhiza, etc. Finally, the paper includes a discussion of translocation phenomena inside plants, of seasonal variation of radionuclide concentrations, and of the expression of radiocontamination of plant material. The expression of radiocesium concentrations on a water basis is suggested as being more appropriate than the usual expression on a dry weight basis for the solution of several radioecological problems.



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## Bryophytes as indicators of radiocesium deposition in northeastern Italy

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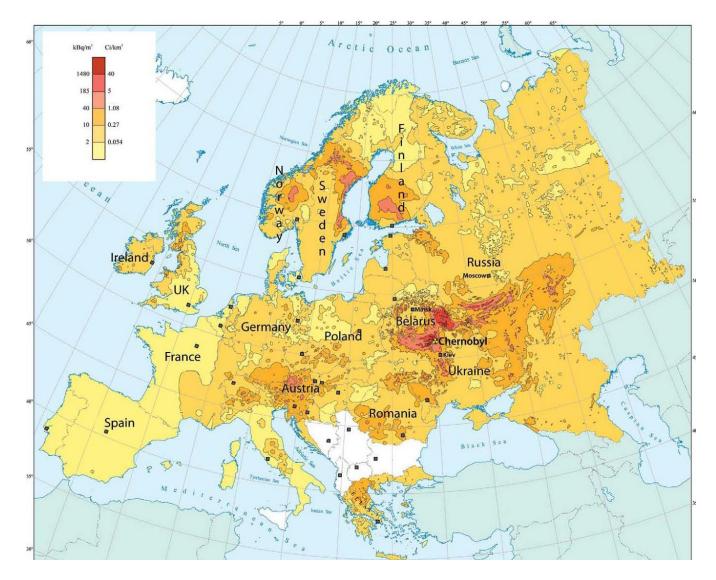
#### Abstract

Samples of moss carpets growing in forest vegetation have been used to map radioactive fallout in northeastern Italy. The main factors affecting data variability are the inclination of the carpets, water absorbing power, and their thickness. The best suited bioindicator proved to be *Ctenidium molluscum*. The results indicate that these carpets were able to intercept most of the radiocesium deposited after the Chernobyl accident, and that the removal half-time in the survey area is of  $\sim 46$  months.

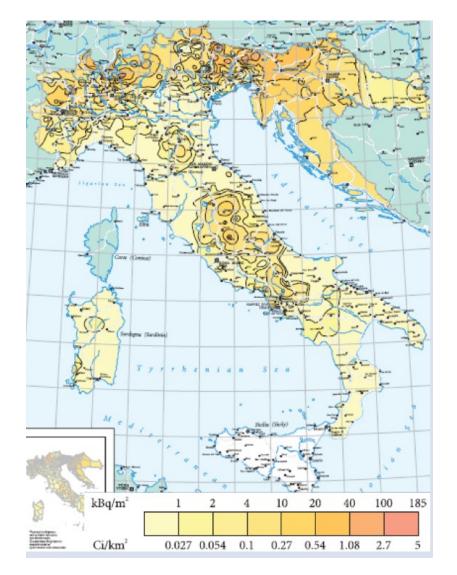
# Assessing radiocontamination in forest ecosystems

**Pier Luigi Nimis** 

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Radiocontamination patterns in Europe after the Chernobyl accident (April, 26th, 1986)



In Italy the highest deposition was in the eastern Alps...



...in an area corresponding to the administrative region of Friuli Venezia Giulia...



...where the Regional Authorities set up a Radioprotection Committee a few days after the accident

### 1 - mushrooms are complex

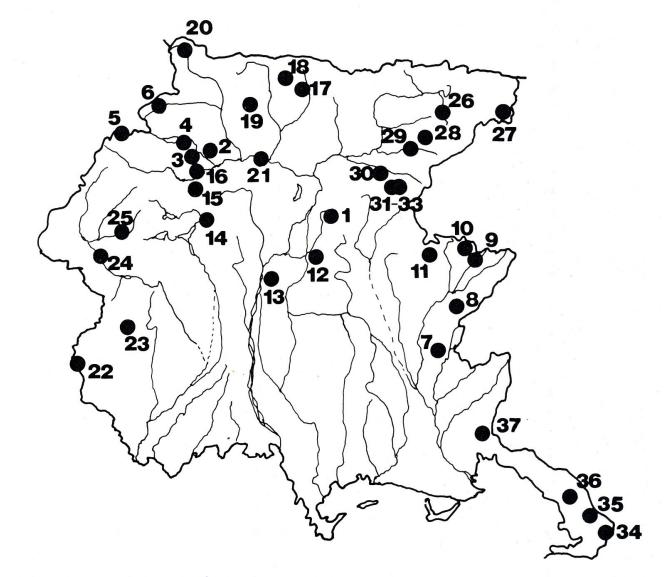


The first data showed high contamination levels in wild mushrooms. No geographic pattern, just a rise of radiocontamination values in August

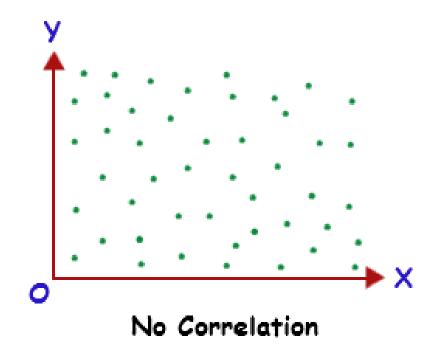




Measures were expressed in Bq/kg **fresh weight**! This makes sense for radioprotection, not for radioecology. The higher values in August were due to dehydration of carpophores due to low precipitations



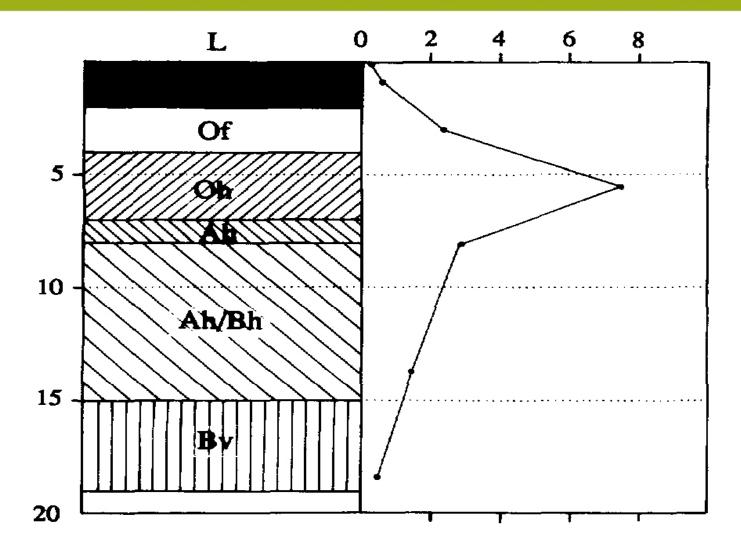
Location of the 37 sampling stations (mushrooms) in forest areas (late summer 1986): 298 samples, 120 species



The analysis of all data revealed no geographic pattern, while differences among species of the same site were considerable



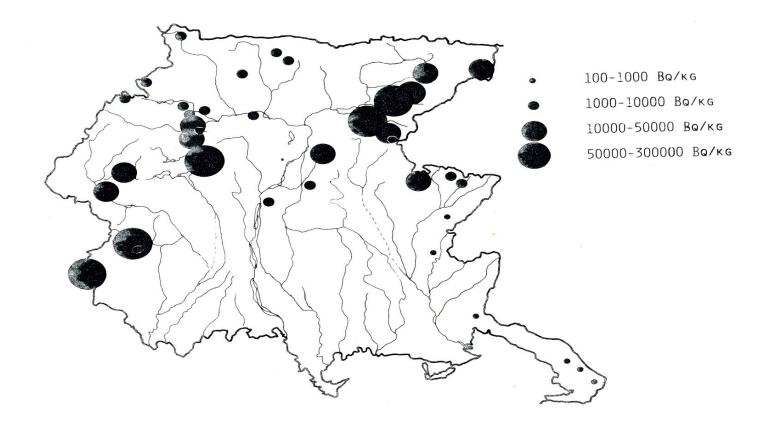
Compared with agricultural soils, forest soils are much more structured



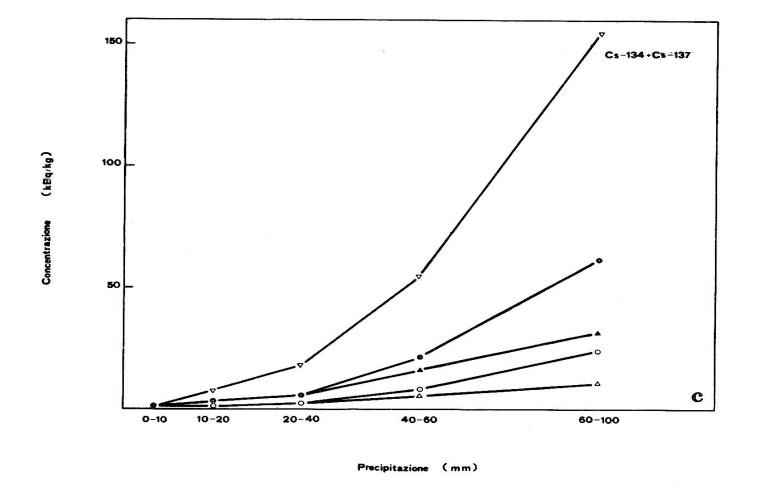
In 1986 most of the radiocesium was concentrated in the upper (organic) soil layers



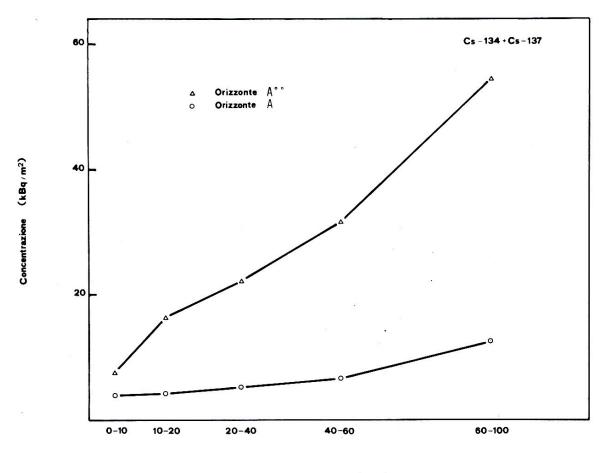
Introducing the difference between **mycorrhizal** and **saprophytic** fungi: the mycelium of the former occupies much deeper soil layers



By using saprophytic fungi alone (i.e. those with a superficial mycelium), a **clear geographic pattern** appears

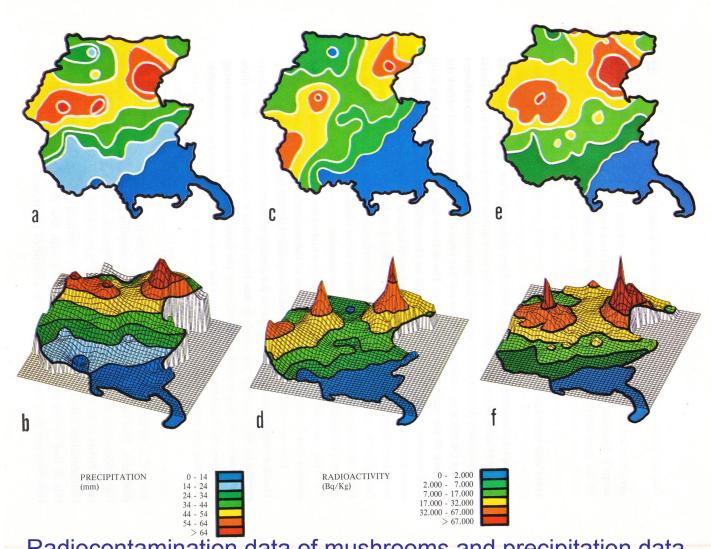


Radiocontamination of saprophytic fungi was correlated with the amount of precipitation in the 7 days following the Chernobyl accident

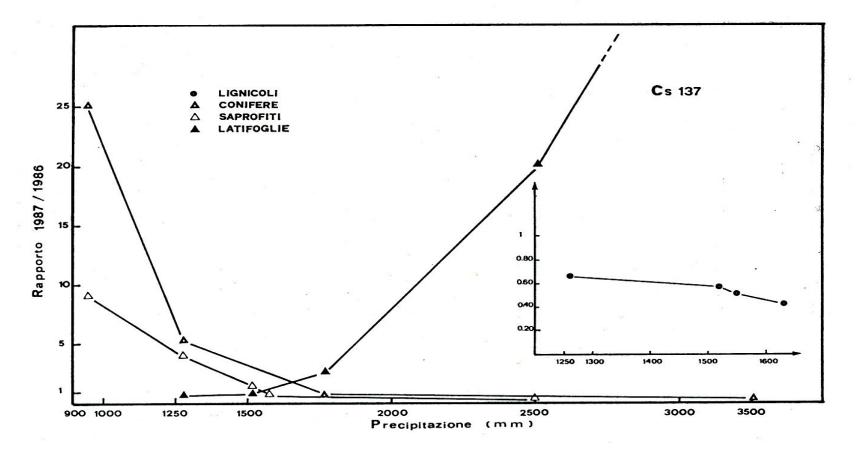


Precipitazione (mm)

The same pattern applies to the most superficial (organic) soil layer, where most of the radiocesium was concentrated

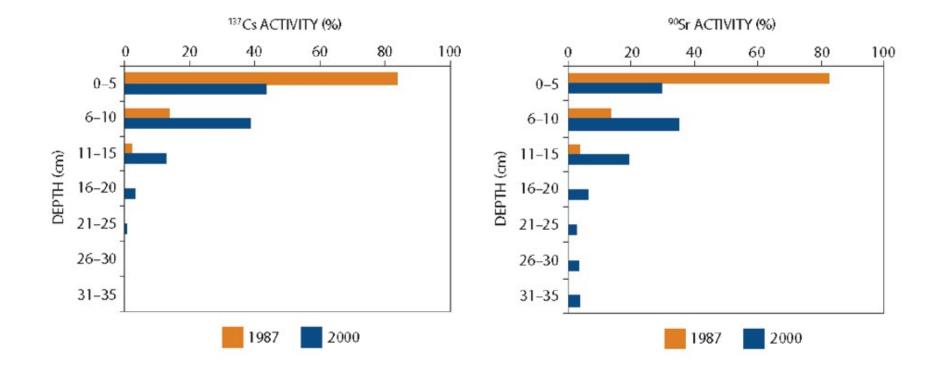


Radiocontamination data of mushrooms and precipitation data were used to construct a **spatial model of the radiocontamination** of mushrooms over the entire region

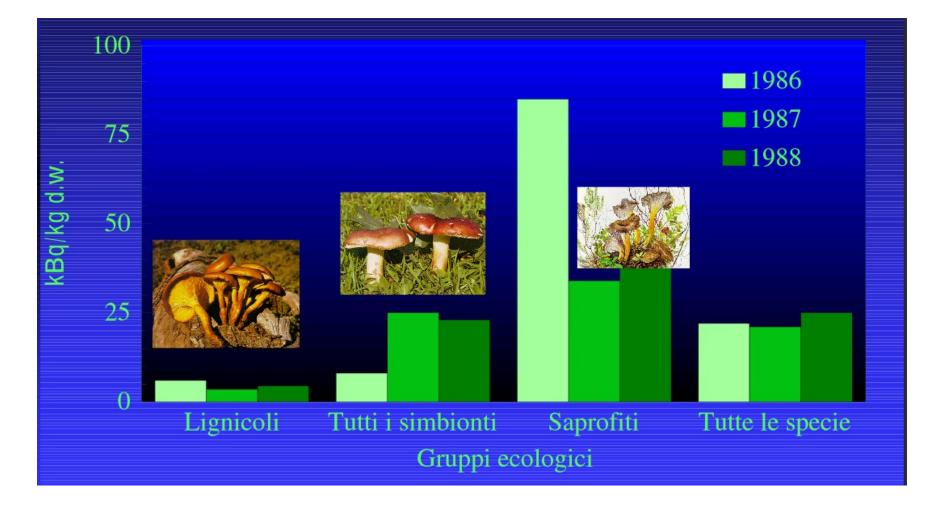


#### Monitoring the situation one year later:

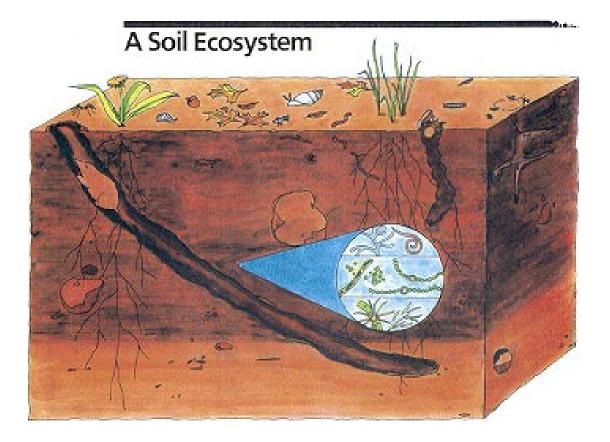
 in low-precipitation areas the radiocontamination of mushrooms with superficial mycelium increased (input from tree crowns in autumn 1986)
 2) In high-precipitation areas the radiocontamination of mycorrhizal mushrooms increased (higher migration into deeper soil layers)



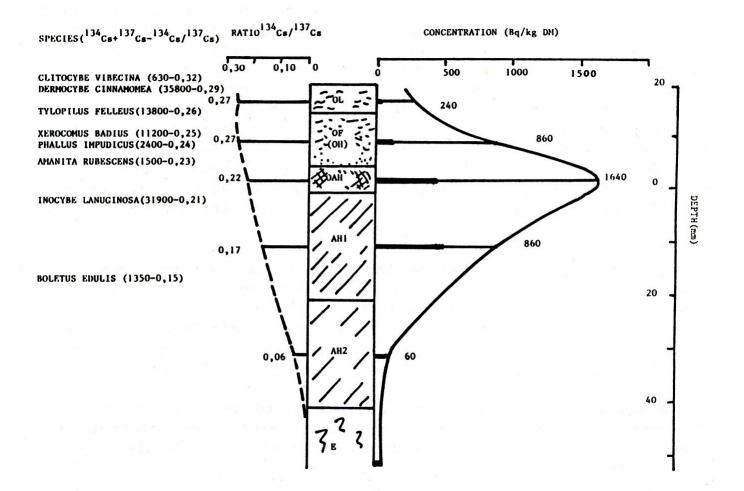
Monitoring the situation 4 years later: most of the radiocesium is still retained in the upper (organic) soil layers...



...and saprophytic fungi still have the highest radiocontamination



Biological retention of radiocaesium in the organic soil layers is high, considerably slowing down its migration into deeper soil layers



The **ratio Cs134/Cs137** (0.27 at the time of the Chernobyl accident) clearly decreased with mycelium depth... (from Guillitte et al., 1990)

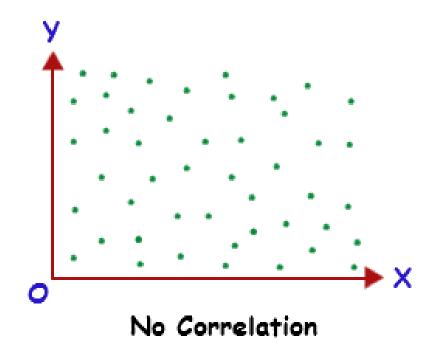


...likely showing the **pre-Chernobyl contamination** due to the nuclear tests of the '60s

# 2 The radioecology of vascular plants in forest ecosystems is complex as well



A case study: radiocontamination of leaves, stems and roots of the total flora in a beech forest (48 species)



The analysis of data (expressed in Bq/kg) showed no correlation with any ecological parameter...

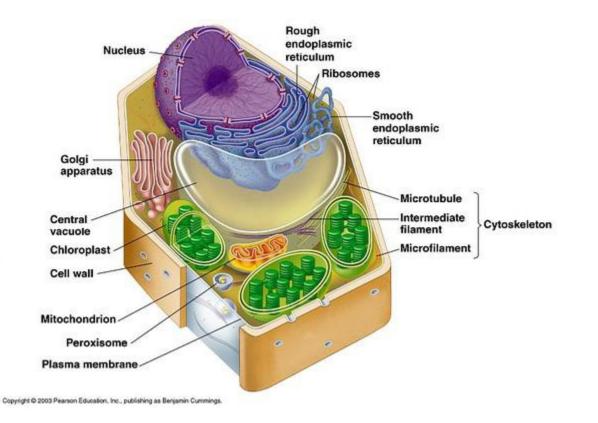
Only clear result: leaves were much more contaminated than roots





Except in an outlier: a plant with fleshy roots with very high radiocontamination leves!





#### A basic difference between animal and plant cells: the wall





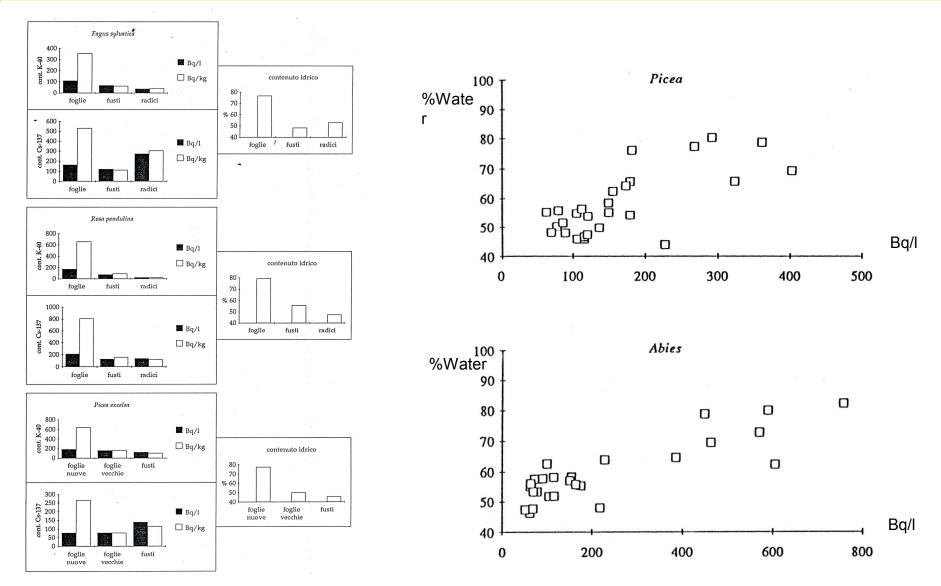


**Bq/kg or Bq/l ?** – An example by analogy

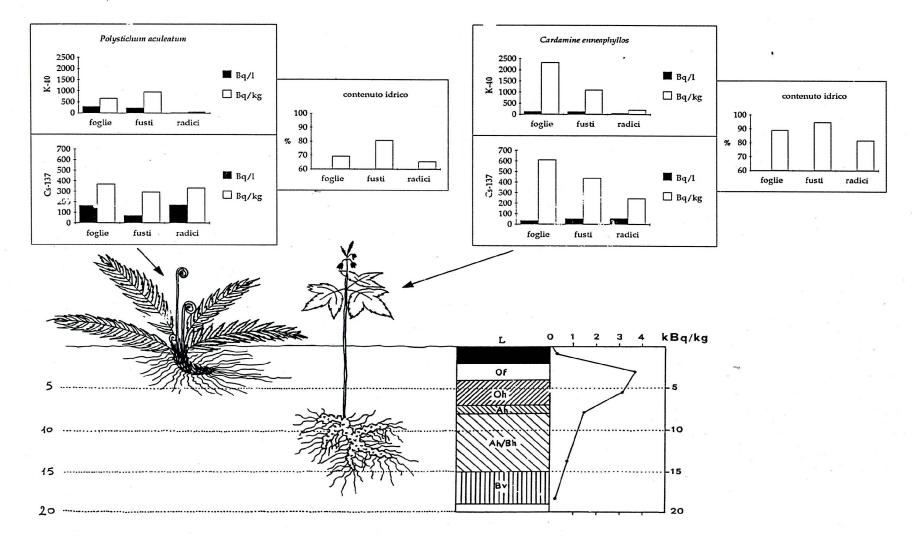




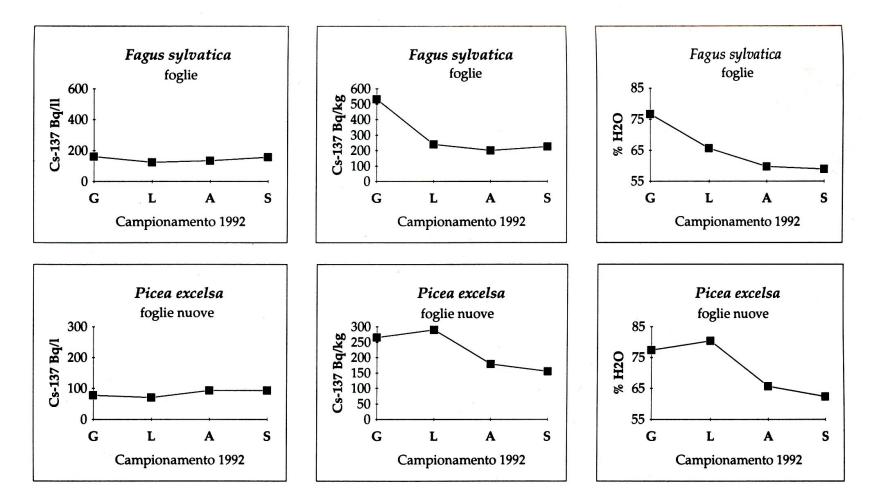
#### **Bq/kg or Bq/l ?** – An example by analogy



The expression of data in Bq/kg (dry weight) mainly reflects the **amount of water** present in the plant material...



## ...introducing a **consistent source of bias** in radioecological research



...which can bring to false results

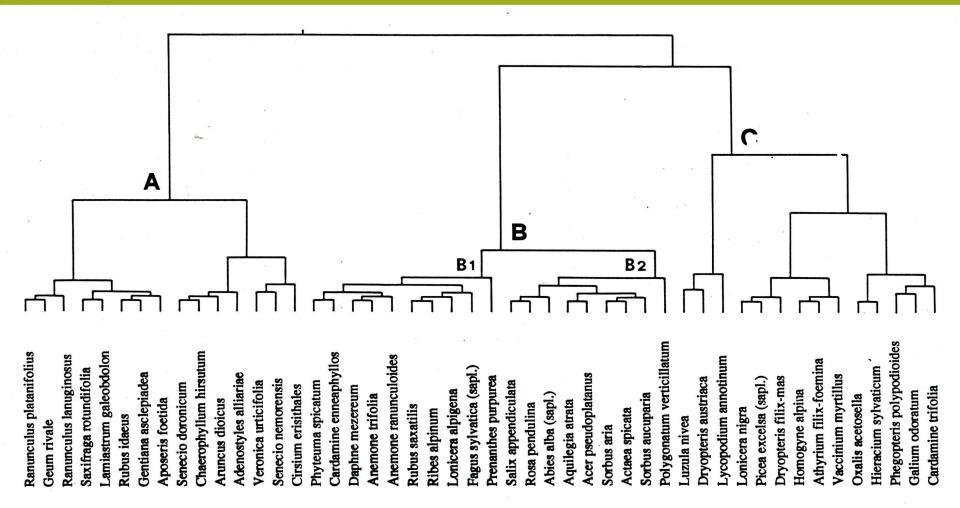
(e.g. translocation of radiocaesium within different parts of a plant)

$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	Radioecological variables of the 48 vascular plant species							
$\begin{array}{c} \text{Annumbus large productions} \\ \text{Rearn rises} \\ \text$		<sup>137</sup> Cs/ <sup>134</sup> Cs	$Cs_r/Cs_1$	Cs <sub>tot</sub> (Bq/l)	<sup>40</sup> K(Bq/l)	${}^{40}K_r/{}^{40}K_1$	Root depth (cm)	
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Phyteuma spicatum4.881.291021610.3319.3Cardamine enneaphyllos5.051.311091570.556.6Daphne mezereum5.441.62541010.5650.0Anemone trifolia5.331.80761640.424.7Anemone rannaculoides5.331.80761660.894.7Rubus saxatilis5.011.561731050.384.6Ribes alpinum5.401.361881430.9650.0Lonicera alpigena4.812.331481830.5850.0Prenanthes purpures5.460.912711480.5214.3Salix appendiculata7.950.8269840.2850.0Acer seudoplatanus7.451.61501690.6535.0Acer seudoplatanus7.431.71862020.3860.0Sorbus aria6.221.32891100.4160.0Actarea spicata6.451.461521890.99-Sorbus aria6.221.32891100.4160.0Polygonatum tericillatum11.330.65241160.3625.0Lucula nitea4.573.8912152950.534.6Dyopteris austriaca5.360.5813011510.208.0Lycopodium anontum4.822.89 <t< td=""><td></td><td></td><td></td><td></td><td></td><td>2.73</td><td>42.0</td></t<>						2.73	42.0	
$ \begin{array}{c} eq:approximate prime and prime $	Custum cristinuics	5.40	13.11	02				
Daphne mezereum5.441.62541010.5650.0Anemone trifola5.441.57651640.424.7Anemone traunaculoides5.331.80761660.894.7Rubus saxatilis5.011.561731050.384.6Ribes alpinum5.401.361881430.9650.0Lonicera alpigena4.812.331481830.5850.0Fagus syltatica (sapl.)5.232.072271470.9920.0Prenanthes purpurea5.460.912711480.5214.3Salix appendiculata7.950.8269840.2850.0Rosa pendulina7.620.711421321.1150.0Advise alba (sapl.)6.260.45951050.9020.0Aquileegia atrata7.451.61501690.6535.0Acer pseudoplatanus7.431.71862020.3860.0Sorbus aria6.221.32891100.4160.0Actaea spicata6.451.461521890.99-Sorbus aucuparia7.081.692211520.5160.0Polygoriatum verticillatum11.330.65241160.3625.0Luzula nitea4.573.8912152950.534.6Dyopteris austrica5.360.58 </td <td>Phyteuma spicatum</td> <td>4.88</td> <td>1.29</td> <td></td> <td></td> <td></td> <td></td>	Phyteuma spicatum	4.88	1.29					
Depine intervalDepine interv	Cardamine enneaphyllos	5.05	1.31	109	157			
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	Daphne mezereum	5.44	1.62	54	101			
Rubus saxailis5.011.561731050.384.6Ribus saxailis5.011.361881430.9650.0Lonicera alpigena4.812.331481830.5850.0Fagus sylvatica (sapl.)5.232.07271470.9920.0Prenanthes purpurea5.460.912711480.5214.3Salix appendiculata7.950.8269840.2850.0Rosa pendulina7.620.711421321.1150.0Abies alba (sapl.)6.260.45951050.9020.0Aquileegia atrata7.451.61501690.6535.0Accer pseudoplatanus7.431.71862020.3860.0Sorbus aria6.221.32891100.4160.0Actaea spicata6.451.461521890.99-Sorbus aucuparia7.081.692211520.5160.0Polygonatum verticillatum11.330.65241160.3625.0Luzula nivea4.573.8912152950.534.6Dryopteris austriaca5.360.5813011510.208.0Lycopodium annotinum4.822.892911140.811.0Lonicera nigra5.280.632561990.1950.0Precea excelsa (sapl.)5.55 <t< td=""><td>Anemone trifolia</td><td>5.48</td><td>1.57</td><td>65</td><td>164</td><td>0.42</td><td>4.7</td></t<>	Anemone trifolia	5.48	1.57	65	164	0.42	4.7	
Natural5.011.501.501.601.6050.0Lonicera alpigena4.812.331481830.5850.0Fagus sylvatica (sapl.)5.232.072271470.9920.0Prenanthes purpurea5.460.912711480.5214.3Salix appendiculata7.950.8269840.2850.0Rosa pendulina7.620.711421321.1150.0Abies alba (sapl.)6.260.45951050.9020.0Aquileegia atrata7.451.61501690.6535.0Acer pseudoplatanus7.431.71862020.3860.0Sorbus aria6.221.32891100.4160.0Actaca spicata6.451.461521890.99Sorbus aucuparia7.081.692211520.5160.0Polygonatum verticillatum11.330.65241160.3625.0Luzula nivea4.573.8912152950.534.6Dryopteris austriaca5.360.5813011510.208.0Lyccopodium annotinum4.822.892911140.811.0Lonicera nigra5.280.632561990.1950.0Propteris austriaca5.360.934671460.561.0Dryopteris galix-mas6.27 <t< td=""><td>Anemone ranunculoides</td><td>5.33</td><td>1.80</td><td>76</td><td>166</td><td>0.89</td><td>4.7</td></t<>	Anemone ranunculoides	5.33	1.80	76	166	0.89	4.7	
Note of prime1.001.001.001.001.001.001.001.001.001.001.001.001.001.00Fagus sylvatica (sapl.)5.232.072271.470.9920.0Prenanthes purpurea5.460.912711.480.521.4.3Salix appendiculata7.950.8269840.2850.0Rosa pendulina7.620.711.421.321.1150.0Abies alba (sapl.)6.260.45951050.9020.0Aquilegia atrata7.451.61501690.6535.0Acer pseudoplatanus7.431.71862020.3860.0Sorbus aria6.221.32891100.4160.0Actae spicata6.451.461521890.99Sorbus acuparia7.081.692211520.5160.0Polygonatum verticillatum11.330.65241160.3625.0Luzula nivea4.573.8912152950.534.6Dryopteris austriaca5.360.5813011510.208.0Lycopodium annotinum4.822.8922911140.811.0Locitera nigra5.250.973401161.1120.0Dryopteris filix-mas6.270.553321630.299.5Homogyne alpina4.560	Rubus saxatilis	5.01	1.56	173	105	0.38	4.6	
Lonicera alpigena4.812.331481830.5850.0Fagus sylvatica (sapl.)5.232.072271470.9920.0Prenanthes purpurea5.460.912711480.5214.3Salix appendiculata7.950.8269840.2850.0Rosa pendulina7.620.711421321.1150.0Abies alba (sapl.)6.260.45951050.9020.0Aquileegia atrata7.431.61501690.6535.0Accer pseudoplatanus7.431.71862020.3860.0Sorbus aria6.221.32891100.4160.0Actaea spicata6.451.461521890.99Sorbus acuparia7.081.692211520.5160.0Polygonatum verticillatum11.330.65241160.3625.0Luzula nivea4.573.8912152950.534.6Dryopteris austriaca5.360.5813011510.208.0Lycopodium annotinum4.822.892911140.811.0Locicera nigra5.280.632561990.1950.0Prece accelsa (sapl.)5.550.973401161.1120.0Dryopteris filix-mas6.270.553321630.299.5Homogyne alpina4.56	Ribes alpinum	5.40	1.36	188	143	0.96	50.0	
Fagus sylvitica (sapl.) $5.23$ $2.07$ $227$ $147$ $0.99$ $20.0$ Prenanthes purpurea $5.46$ $0.91$ $271$ $148$ $0.52$ $14.3$ Salix appendiculata $7.95$ $0.82$ $69$ $84$ $0.28$ $50.0$ Rosa pendulina $7.62$ $0.71$ $142$ $132$ $1.11$ $50.0$ Abies alba (sapl.) $6.26$ $0.45$ $95$ $105$ $0.90$ $20.0$ Aquileegia atrata $7.45$ $1.61$ $50$ $169$ $0.65$ $35.0$ Acer pseudoplatanus $7.43$ $1.71$ $86$ $202$ $0.38$ $60.0$ Sorbus aria $6.22$ $1.32$ $89$ $110$ $0.41$ $60.0$ Actra pseudoplatanus $7.43$ $1.76$ $125$ $0.51$ $60.0$ Sorbus aria $6.45$ $1.46$ $152$ $189$ $0.99$ $-$ Sorbus aucuparia $7.08$ $1.69$ $221$ $152$ $0.51$ $60.0$ Polygonatum verticillatum $11.33$ $0.65$ $24$ $116$ $0.36$ $25.0$ Luzula nivea $4.57$ $3.89$ $1215$ $295$ $0.53$ $4.6$ Dryopteris austriaca $5.36$ $0.58$ $1301$ $151$ $0.20$ $8.0$ Lycopodium annotinum $4.82$ $2.89$ $2291$ $114$ $0.81$ $1.0$ Lonicera nigra $5.28$ $0.63$ $256$ $199$ $0.19$ $50.0$ Prece axcelsa (sapl.) $5.55$ $0.97$ $340$ $116$		4.81	2.33	148	183	0.58	50.0	
Prenanthes purpurea5.460.912711480.5214.3Salix appendiculata7.950.8269840.2850.0Rosa pendiculata7.950.8269840.2850.0Rosa pendiculata7.620.711421321.1150.0Abies alba (sapl.)6.260.45951050.9020.0Aquileegia atrata7.451.61501690.6535.0Acer pseudoplatanus7.431.71862020.3860.0Sorbus aria6.221.32891100.4160.0Actaea spicata6.451.461521890.99-Sorbus avcuparia7.081.692211520.5160.0Polygonatum verticillatum11.330.65241160.3625.0Luzula nivea4.573.8912152950.534.6Dryopteris austriaca5.360.5813011510.208.0Lycopodium annotinum4.822.892911140.811.0Lonicera nigra5.280.632561990.1950.0Propeter filts-mas6.270.553321630.299.5Homogyne alpina4.560.934671460.561.0Athyrium filts-foemina5.380.724501520.1610.2Vaccinium myrtillus5.64 <td< td=""><td></td><td>5.23</td><td>2.07</td><td>227</td><td>147</td><td>0.99</td><td>20.0</td></td<>		5.23	2.07	227	147	0.99	20.0	
Salix appendiculata7.95 $0.82$ 6984 $0.28$ 50.0Rosa pendulina7.62 $0.71$ $142$ $132$ $1.11$ $50.0$ Abies alba (sapl.) $6.26$ $0.45$ $95$ $105$ $0.90$ $20.0$ Aquileegia atrata7.45 $1.61$ $50$ $169$ $0.65$ $35.0$ Acer pseudoplatanus7.43 $1.71$ $86$ $202$ $0.38$ $60.0$ Sorbus aria $6.22$ $1.32$ $89$ $110$ $0.41$ $60.0$ Actae spicata $6.45$ $1.46$ $152$ $189$ $0.99$ $$ Sorbus aucuparia $7.08$ $1.69$ $221$ $152$ $0.51$ $60.0$ Polygonatum vericillatum $11.33$ $0.65$ $24$ $116$ $0.36$ $250$ Luzula nivea $4.57$ $3.89$ $1215$ $295$ $0.53$ $4.6$ Dryopteris austriaca $5.36$ $0.58$ $1301$ $151$ $0.20$ $8.0$ Lycopodium annotinum $4.82$ $2.89$ $2291$ $114$ $0.81$ $1.0$ Lonicera nigra $5.28$ $0.63$ $256$ $199$ $0.19$ $50.0$ Pryopteris filtx-mas $6.27$ $0.55$ $332$ $163$ $0.29$ $9.5$ Homogyne alpina $4.56$ $0.93$ $467$ $146$ $0.56$ $1.0$ Athyrium filtx-foemina $5.38$ $0.72$ $450$ $152$ $0.16$ $10.2$ Vaccinium myritilus $5.64$ $1.60$ $376$ $179$ <t< td=""><td></td><td>5.46</td><td>0.91</td><td>271</td><td>148</td><td>0.52</td><td>14.3</td></t<>		5.46	0.91	271	148	0.52	14.3	
Rosa pendulina7.620.711421321.1150.0Abies alba (sapl.)6.260.45951050.9020.0Aquilegia atrata7.451.61501690.6535.0Acer pseudoplatanus7.431.71862020.3860.0Sorbus aria6.221.32891100.4160.0Actae spicata6.451.461521890.99Sorbus avia6.451.461521890.99Sorbus avicuparia7.081.692211520.5160.0Polygonatum verticillatum11.330.65241160.3625.0Luzula nivea4.573.8912152950.534.6Dryopteris austriaca5.360.5813011510.208.0Lycopodium annotinum4.822.8922911140.811.0Locicera nigra5.280.632561990.1950.0Pricea excelsa (sapl.)5.550.973401161.1120.0Dryopteris filix-mas6.270.553321630.299.5Homogyne alpina4.560.934671460.561.0Athyrium filix foemina5.380.724501520.1610.2Vaccinium myriillus5.641.603761790.633.6Oxalis acetosella4.664		7.95	0.82	69	84	0.28	50.0	
Abies alba (sapl.) $6.26$ $0.45$ $95$ $105$ $0.90$ $20.0$ Aquileegia atrata $7.45$ $1.61$ $50$ $169$ $0.65$ $35.0$ Acer pseudoplatanus $7.43$ $1.71$ $86$ $202$ $0.38$ $60.0$ Sorbus aria $6.22$ $1.32$ $89$ $110$ $0.41$ $60.0$ Acter as picata $6.45$ $1.46$ $152$ $189$ $0.99$ $-$ Sorbus aucuparia $7.08$ $1.69$ $221$ $152$ $0.51$ $60.0$ Polygonatum verticillatum $11.33$ $0.65$ $24$ $116$ $0.36$ $25.0$ Luzula nivea $4.57$ $3.89$ $1215$ $295$ $0.53$ $4.6$ Dryopteris austriaca $5.36$ $0.58$ $1301$ $151$ $0.20$ $8.0$ Lycopodium annotinum $4.82$ $2.89$ $2291$ $114$ $0.81$ $1.0$ Lonicera nigra $5.28$ $0.63$ $256$ $199$ $0.19$ $50.0$ Properis filtx-mas $6.27$ $0.55$ $332$ $163$ $0.29$ $9.5$ Homogyne alpina $4.56$ $0.93$ $467$ $146$ $0.56$ $1.0$ Athyrium filtx-foemina $5.38$ $0.72$ $450$ $152$ $0.16$ $10.2$ Vaccinium myrtillus $5.64$ $1.60$ $376$ $179$ $0.63$ $3.6$ Oxalis acetosela $4.66$ $4.91$ $556$ $137$ $1.98$ $1.0$ Hieracium sylvaticum $4.89$ $4.71$ $462$ <td></td> <td>7.62</td> <td>0.71</td> <td>142</td> <td>132</td> <td>1.11</td> <td>50.0</td>		7.62	0.71	142	132	1.11	50.0	
Aquilegia atrita7.451.61501690.6535.0Acer pseudoplatanus7.431.71862020.3860.0Sorbus aria6.221.32891100.4160.0Actaea spicata6.451.461521890.99Sorbus aucuparia7.081.692211520.5160.0Polygonatum verticillatum11.330.65241160.3625.0Luzula nivea4.573.8912152950.534.6Dryopteris austriaca5.360.5813011510.208.0Lycopodium annotinum4.822.8922911140.811.0Lonicera nigra5.280.632561990.1950.0Pice axcelsa (sapl.)5.550.973401161.1120.0Dryopteris filts-mas6.270.553321630.299.5Homogyne alpina4.560.934671460.561.0Athyrium filts-foemina5.380.724501520.1610.2Vaccinium myrtillus5.641.603761790.633.6Oxalis acetosella4.664.915561371.981.0Hieracium sylvaticum4.894.714621481.735.2Phegoperis polypodioides4.633.053301500.764.0Galum dodartum4		6.26	0.45	95	105	0.90	20.0	
Acer pseudoplatanus7.431.71862020.3860.0Sorbus aria6.221.32891100.4160.0Actaea spicata6.451.461521890.99Sorbus acuparia7.081.692211520.5160.0Polygonatum verticillatum11.330.65241160.3625.0Luzula nivea4.573.8912152950.534.6Dryopteris austriaca5.360.5813011510.208.0Lycopodium annotinum4.822.8922911140.811.0Lonicera nigra5.280.632561990.1950.0Picea excelsa (sapl.)5.550.973401161.1120.0Dryopteris filix-mas6.270.553321630.299.5Homogyne alpina4.560.934671460.561.0Athyrium filix-foemina5.380.724501520.1610.2Vaccinium myrtillus5.641.603761790.633.6Oxalis acetosella4.664.915561371.981.0Hieracium sylvaticum4.894.714621481.735.2Phegoperis polypodioides4.633.053301500.764.0Galum odoratum4.402.394611760.731.5		7.45	1.61	50	169	0.65	35.0	
Sorbus aria $6.22$ $1.32$ $89$ $110$ $0.41$ $60.0$ Actaea spicata $6.45$ $1.46$ $152$ $189$ $0.99$ $-$ Sorbus aucuparia $7.08$ $1.69$ $221$ $152$ $0.51$ $60.0$ Polygonatum verticillatum $11.33$ $0.65$ $24$ $116$ $0.36$ $25.0$ Luzula nivea $4.57$ $3.89$ $1215$ $295$ $0.53$ $4.6$ Dryopteris austriaca $5.36$ $0.58$ $1301$ $151$ $0.20$ $8.0$ Lycopodium annotinum $4.82$ $2.89$ $2291$ $114$ $0.81$ $1.0$ Lonicera nigra $5.28$ $0.63$ $256$ $199$ $0.19$ $50.0$ Picea excelsa (sapl.) $5.55$ $0.97$ $340$ $116$ $1.11$ $20.0$ Dryopteris filtx-mas $6.27$ $0.55$ $332$ $163$ $0.29$ $9.5$ Homogyne alpina $4.56$ $0.93$ $467$ $146$ $0.56$ $1.0$ Athyrium filtx-foemina $5.38$ $0.72$ $450$ $152$ $0.16$ $10.2$ Vaccinium myriillus $5.64$ $1.60$ $376$ $179$ $0.63$ $3.6$ Oxalis acetosella $4.66$ $4.91$ $556$ $137$ $1.98$ $1.0$ Hieracium sylvaticum $4.89$ $4.71$ $462$ $148$ $1.73$ $5.2$ Phegoperis polypodioides $4.63$ $3.05$ $330$ $150$ $0.76$ $4.0$ Galum odoratum $4.40$ $2.39$		7.43	1.71	86	202	0.38	60.0	
Actaea spicata $6.45$ $1.46$ $152$ $189$ $0.99$ $$ Sorbus aucuparia $7.08$ $1.69$ $221$ $152$ $0.51$ $60.0$ Polygonatum verticillatum $11.33$ $0.65$ $24$ $116$ $0.36$ $25.0$ Luzula nivea $4.57$ $3.89$ $1215$ $295$ $0.53$ $4.6$ Dryopteris austriaca $5.36$ $0.58$ $1301$ $151$ $0.20$ $8.0$ Lycopodium annotinum $4.82$ $2.89$ $2291$ $114$ $0.81$ $1.0$ Lonicera nigra $5.28$ $0.63$ $256$ $199$ $0.19$ $50.0$ Propeteris filts-mas $6.27$ $0.55$ $332$ $163$ $0.29$ $9.5$ Homogyne alpina $4.56$ $0.93$ $467$ $146$ $0.56$ $1.0$ Athyrium filts-foemina $5.38$ $0.72$ $450$ $152$ $0.16$ $10.2$ Vaccinium myrtillus $5.64$ $1.60$ $376$ $179$ $0.63$ $3.6$ Oxalis acetosella $4.66$ $4.91$ $556$ $137$ $1.98$ $1.0$ Hieracium sylvaticum $4.89$ $4.71$ $462$ $148$ $1.73$ $5.2$ Phegoperis polypodioides $4.63$ $3.05$ $330$ $50$ $0.76$ $4.0$		6.22	1.32	89	110	0.41	60.0	
Sorbus aucuparia         7.08         1.69         221         152         0.51         60.0           Polygonatum verticillatum         11.33         0.65         24         116         0.36         25.0           Luzula nivea         4.57         3.89         1215         295         0.53         4.6           Dryopteris austriaca         5.36         0.58         1301         151         0.20         8.0           Lycopodium annotinum         4.82         2.89         2291         114         0.81         1.0           Lonicera nigra         5.28         0.63         256         199         0.19         50.0           Pricea excelsa (sapl.)         5.55         0.97         340         116         1.11         20.0           Dryopteris filix-mas         6.27         0.55         332         163         0.29         9.5           Homogyne alpina         4.56         0.93         467         146         0.56         1.0           Athyrium filix-foemina         5.38         0.72         450         152         0.16         10.2           Vaccinium myrtillus         5.64         1.60         376         179         0.63         3.6      <				152	189	0.99	_	
Polygonatum verticillatum         11.33         0.65         24         116         0.36         25.0           Luzula nivea         4.57         3.89         1215         295         0.53         4.6           Dryopteris austriaca         5.36         0.58         1301         151         0.20         8.0           Lycopodium annotinum         4.82         2.89         2291         114         0.81         1.0           Lonicera nigra         5.28         0.63         256         199         0.19         50.0           Picea excelsa (sapl.)         5.55         0.97         340         116         1.11         20.0           Dryopteris filix-mas         6.27         0.55         332         163         0.29         9.5           Homogyne alpina         4.56         0.93         467         146         0.56         1.0           Athyrium filix-foemina         5.38         0.72         450         152         0.16         10.2           Vaccinium myrtillus         5.64         1.60         376         179         0.63         3.6           Oxalis acetosella         4.66         4.91         556         137         1.98         1.0 <t< td=""><td></td><td></td><td></td><td>221</td><td>152</td><td>0.51</td><td>60.0</td></t<>				221	152	0.51	60.0	
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Phegoperis polypodioides         4.63         3.05         330         150         0.76         4.0           Galium odoratum         4.40         2.39         461         176         0.73         1.5	Hieracium sylvaticum	4.89	4.71	462	148	1.73		
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	Galium odoratum	4.40	2.39	461	176	0.73		
Cardamine trifolia 4.65 2.33 674 156 0.87 1.1		4.65	2.33	674	156	0.87	1.1	

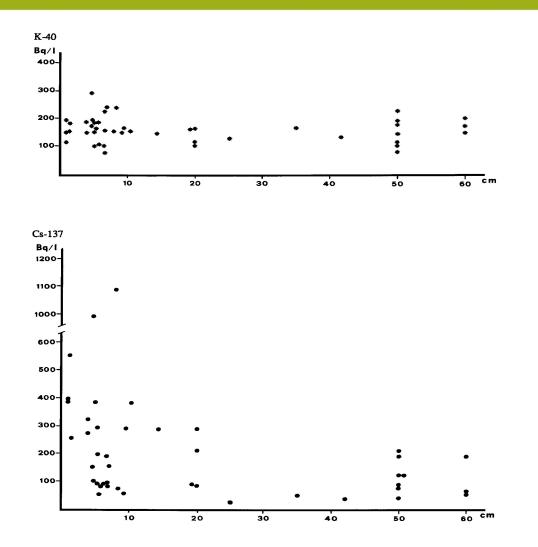
#### Radioecological variables of the 48 vascular plant species

Variables: (1) ccsium-137/ccsium-134; (2) ratio of ccsium-137 roots/leaves; (3) total average radioccsium contamination (Bq/l); (4) total average potassium-40 contamination (Bq/l), (5) ratio of potassium-40 roots/leaves; (6) average root depth (cm).

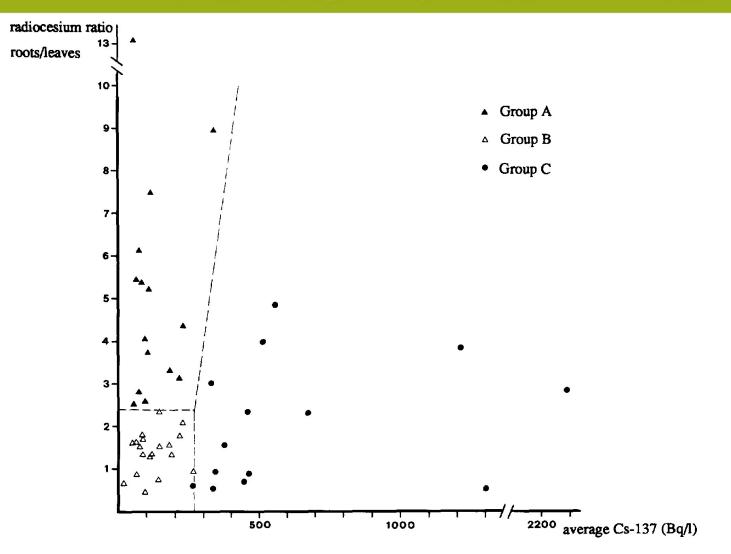
By expressing the data in **Bq/I** (i.e. on the difference between fresh and dry weight...)



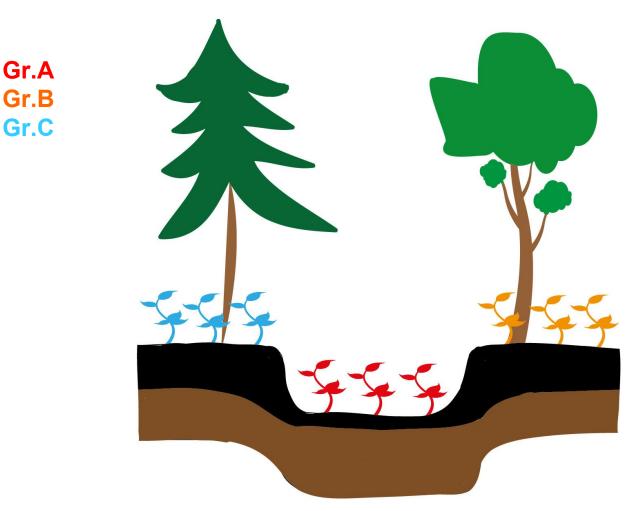
The species are subdivided into 3 clusters corresponding to 3 well-known ecological groups



The radiocontamination of plants is **well correlated** with the average depth of their rooting systems...



...and the 3 groups of species are **neatly separated by some radioecological variables** 



Lessons learnt: 1) radiocontamination patterns in forest ecosystems may be very complex. 2) Expressing radiocaesium data in Bq/I permits to disentangle this complexity.

# 3 – With mosses it's easier!



The regional authorities wanted a **bioaccumulator** to rapidly map the extent of radiocontamination all over the region

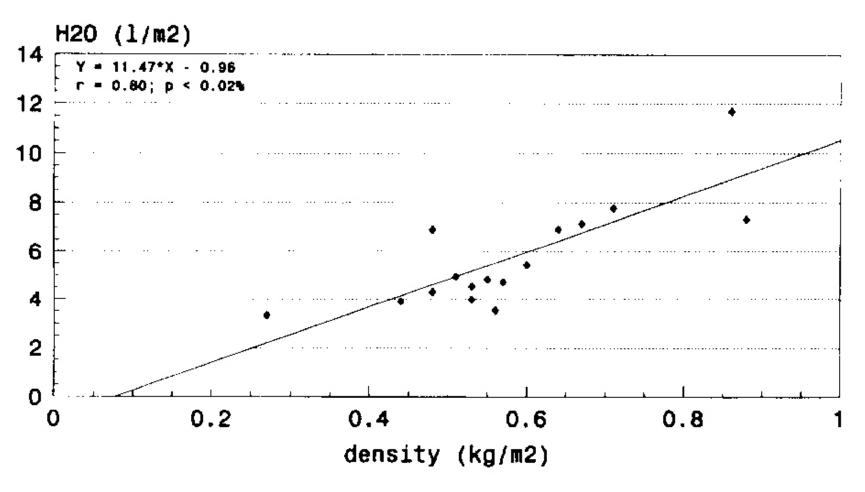


Advantages of using moss carpets:
1) They produce a very homogeneous soil, withour mineral inclusions

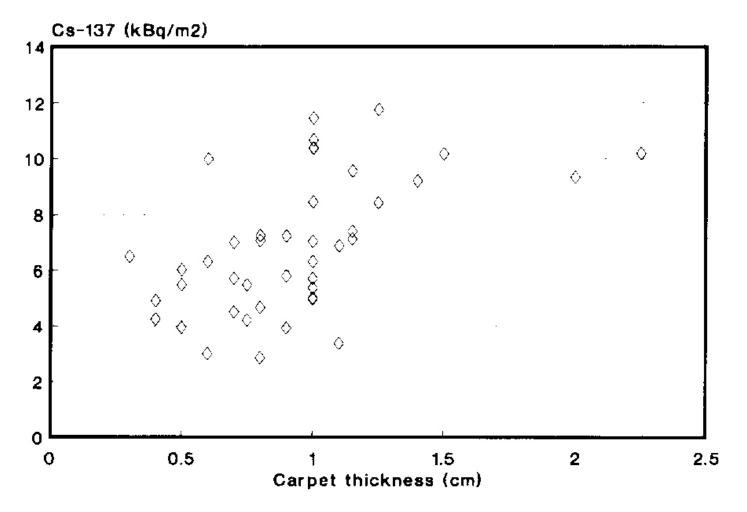
#### Advantages of using moss carpets:

2) They can be easily cut into geometrical forms (assessing radiocontamination per unit area)





Developing a sampling protocol, **1st step**: assessing the absorbing power of moss carpets (in terms of density): moss carpet can absorb up to 12 I of water per square meter



Developing a sampling protocol, **2nd step**: assessing the absorbing power of moss carpets: the absorbing power **is related to carpet thickness** 

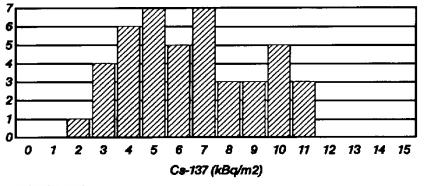


The selected bioaccumulator: *Ctenidium molluscum* (high absorbing power, widespread and common in forests ecosystems)



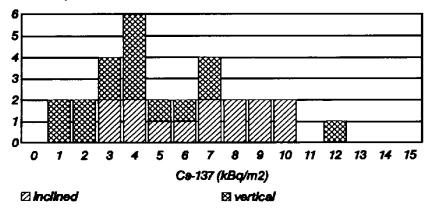
Reducing data variability: inclination has an effect on radiocontamination values

#### nr. of samples

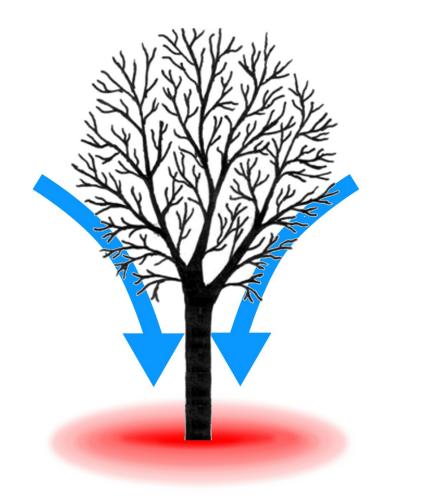


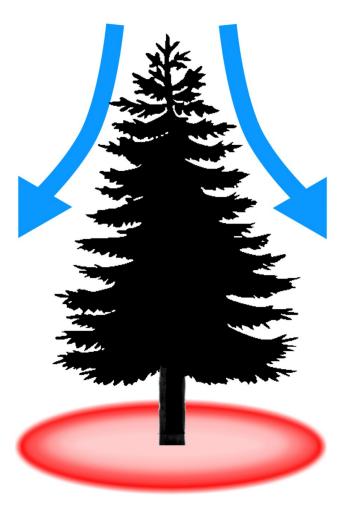
A horizontal



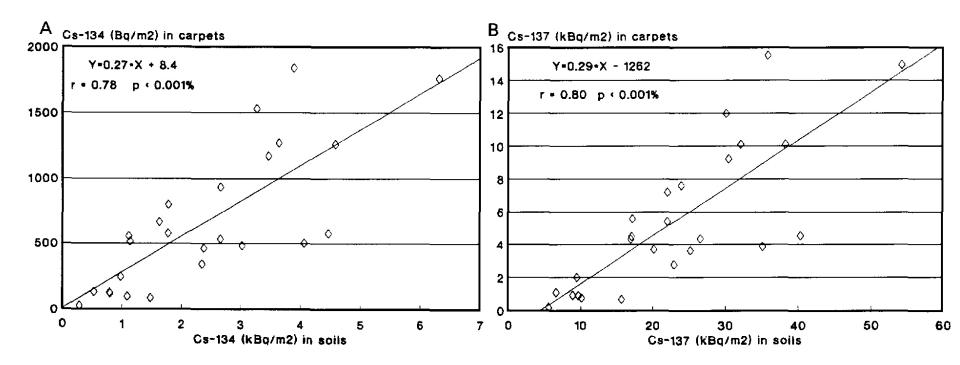


Developing a sampling protocol, **3rd step**: assessing the influence of inclination on the radiocontamination of moss carpets

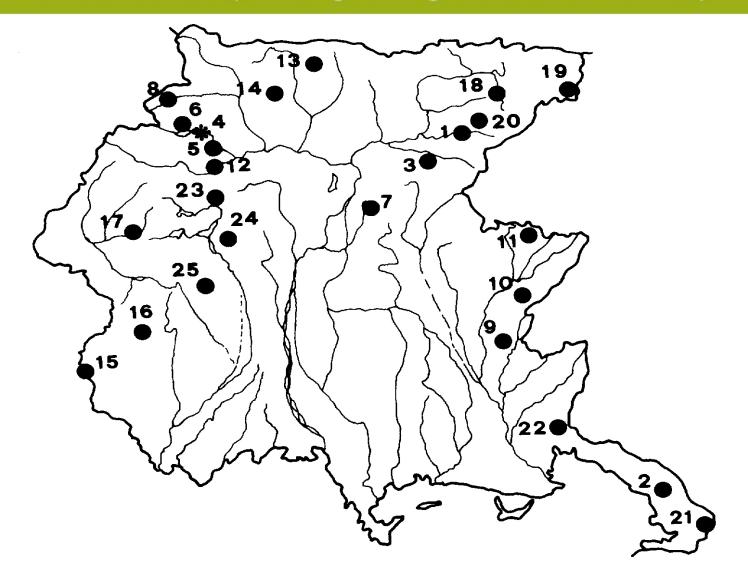




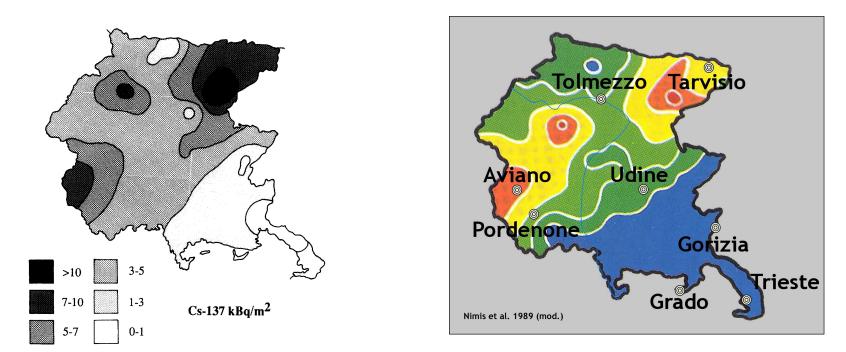
Developing a sampling protocol, **4th step**: assessing the effect of tree crown geometry on radiodeposition



Testing the sampling protocol: **predictive value** of moss data versus soil data



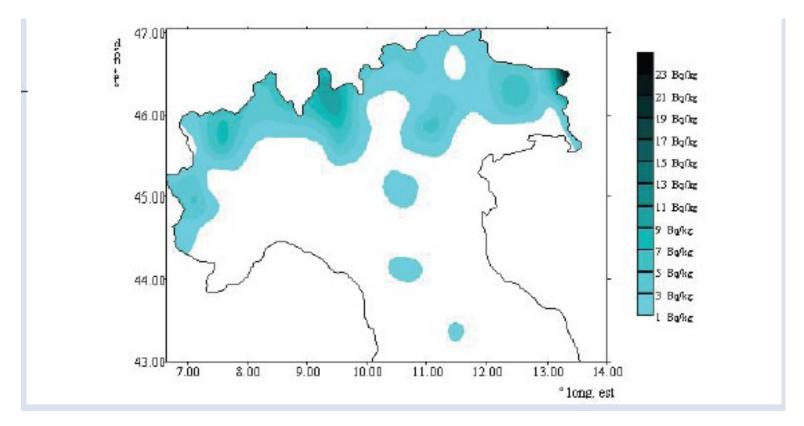
Testing the sampling protocol: the 1990 campaign



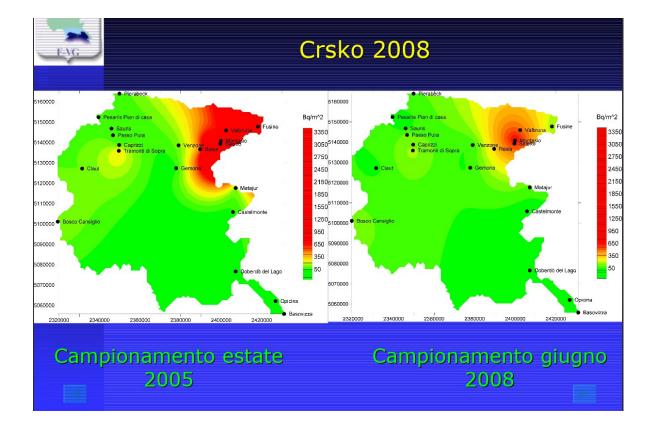
Mosses 1990 (Bq/m<sup>2</sup>)

Mushrooms 1986 (Bq/kg)

The results of the 1990 campaign (less than a week): mosses are optimal bioaccumulators!

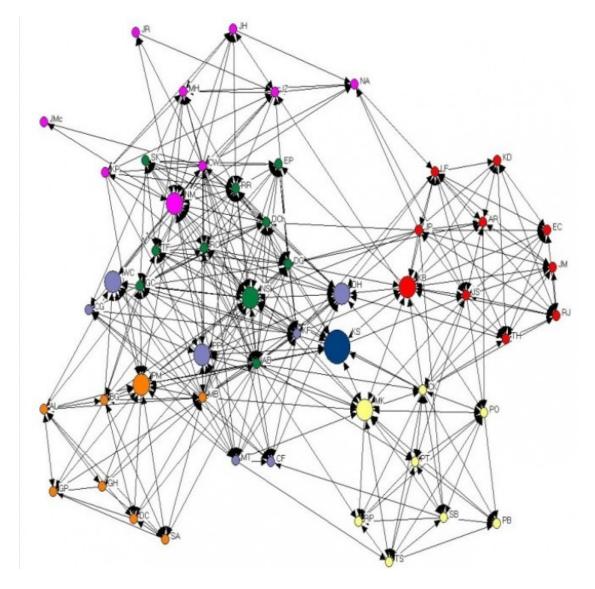


Our protocol was **adopted at the National level** to monitor radiodeposition in forest ecosystems...



...and proved to be useful for the **rapid assessment** of radiocontamination after an accident (Crsko, Slovenia, 2008)

### 4 - Final remarks: the complexity of forest ecosystems



**Final remarks**: historically, radioecoloogy developed from radioprotection: the first studies and models were mainly carried out in simple agroecosystems.



Final remarks: however, agroecosystems and forest ecosystems are widely different



1) In forests, plants avoid root competition by exploring different soil layers with different biological, chemical and physical characteristics,

2) many plant species are in mycorrhizal symbiosis with fungi,

3) Microgeomorphological variation may induce sharp micropatterns in soil radiocontamination.

 Thus, spatially contiguous plants might root in widely different soil types. Final remarks: in complex forest ecosystems the aims of radioecology and radioprotection do not always coincide.



Different approaches are often needed for different aims. However, radioecology is fundamental to develop predictive models which are of basic importance for radioprotection.

# Thank you for the attention !