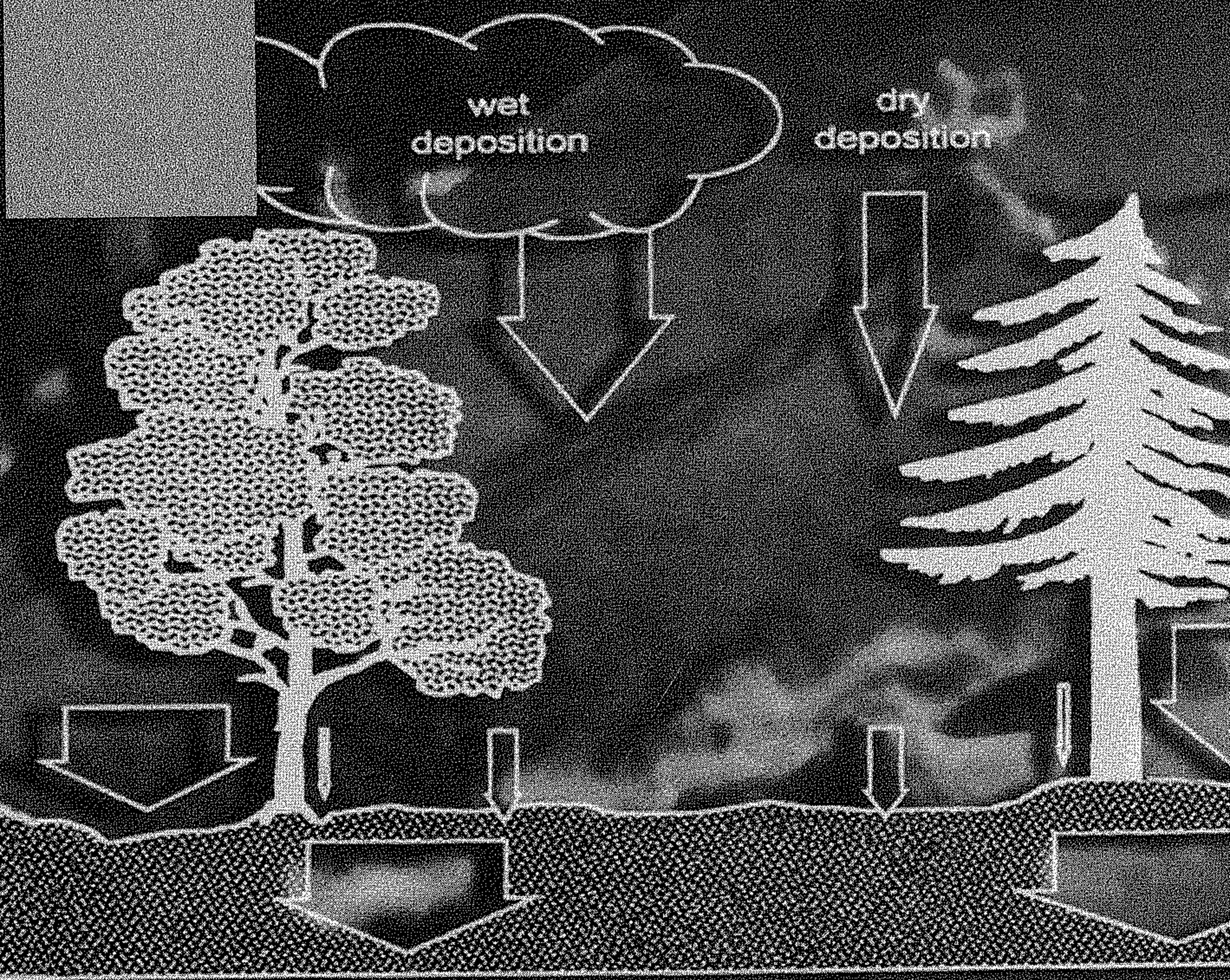


R. Bargagli

# Trace Elements in Terrestrial Plants

An Ecophysiological Approach  
to Biomonitoring and Biorecovery



Springer

# CONTENTS

<b>1. Chemical Elements and Plant Life</b> .....	<b>1</b>
Introduction .....	1
Chemical Properties and Abundance of Elements .....	3
Trace Elements and Plant Nutrition .....	5
Deficiency, Interaction and Toxicity of Trace Elements .....	9
Development of Metal Tolerance by Plants .....	12
Plants as Indicators of Ore Bodies and Environmental Pollution .....	15
Conclusion .....	19
<b>2. Soil Geochemistry and Anthropogenic Modification of Element Bioavailability</b> .....	<b>23</b>
Introduction .....	23
Soil Formation and Composition .....	25
Trace Element Geochemistry .....	28
Soil Organisms .....	31
Element Availability to Plants .....	34
Element Uptake and Transport by Plants .....	37
Soil Pollution .....	40
Conclusion .....	43
<b>3. The Emission and Dispersal of Atmospheric Trace Elements</b> .....	<b>49</b>
Introduction .....	49
Composition of the Atmosphere .....	50
Emission of Atmospheric Trace Elements .....	54
Atmospheric Dispersal of Pollutants .....	59
Wet Deposition .....	62
Dry Deposition .....	64
Spatio-Temporal Trends in Global Atmospheric Trace Element Deposition .....	65
Mercury Cycling in the Atmosphere—A Case Study .....	69
Conclusion .....	72
<b>4. Plants as Biomonitors of Atmospheric Pollutants</b> .....	<b>79</b>
Introduction .....	79
Biomonitors Defined .....	80
Mechanisms of Plant Injury by Pollutants .....	81
Evaluation of Plant Injury .....	84
Remote Sensing and Plant Injury .....	88
Indirect Injury and the Predisposition of Trees to Stress .....	89
Advantages and Disadvantages of Biological and Instrumental Monitoring .....	91
Choosing a Monitoring System .....	93

Why Does Biomonitoring Not Play a Greater Role in Environmental Management? .....	97
Proceeding with Trace Element Biomonitoring— A Conclusion .....	99

<b>5. Selection, Sampling and Preparation of Plants for Trace Element Analysis .....</b>	<b>105</b>
Introduction .....	105
Planning of Trace Element Biomonitoring .....	106
Selection of Biomonitors .....	108
Sampling Design .....	112
Quality Control of Sampling .....	116
Cleaning of Samples .....	119
Soil Contamination of Plant Samples .....	120
Drying, Homogenization and Storage of Samples .....	122
Conclusion .....	123
<b>6. Analytical Determinations and Data Interpretation .....</b>	<b>127</b>
Introduction .....	127
Sample Decomposition .....	128
Avoidance of Systematic Errors .....	132
Element Detection Limits .....	133
Methods of Instrumental Analysis of Plant Samples .....	134
Choosing Analytical Methods for Biomonitoring .....	137
Standard Reference Materials .....	143
Background Concentrations .....	145
Data Evaluation and Management .....	146
Conclusion .....	149
<b>7. Fungi and Higher Plants as Biomonitors of Trace Elements in Soil .....</b>	<b>153</b>
Introduction .....	153
Ecophysiology of Fungi and Interactions with Trace Elements .....	154
Element Cycling by Saprophytic and Mycorrhizal Fungi ....	155
Metal Accumulation by Macrofungi .....	158
Using Higher Fungi as Soil Pollutant Biomonitors .....	162
Contributions of Soil and Air to Trace Elements in Higher Plants .....	165
Accumulation of Soilborne Metals by Wild Plants .....	167
Metal Transfer from Soil to Crop Plants .....	170
Conclusion .....	172

<b>8. Lichens as Biomonitors of Airborne Trace Elements .....</b>	<b>179</b>
Introduction .....	179
Element Uptake and Accumulation in Lichens .....	180
Metal Tolerance of Lichens and Species Selection for Biomonitoring .....	184
Sampling and Analytical Protocol .....	186
Background Concentrations of Trace Elements in Lichens .....	189
Influence of the Substrate on Lichen Elemental Composition .....	191
Correlations Between Trace Element Concentrations in Atmospheric Deposition and in Lichens .....	193
Trace Element Monitoring Using Lichen Transplants .....	196
Differentiating Sources of Trace Elements Found in Lichens .....	197
Conclusion .....	200
<b>9. Mosses as Passive and Active Biomonitors of Trace Elements .....</b>	<b>207</b>
Introduction .....	207
Ecophysiology and Metal Tolerance of Mosses .....	208
Moss Species for Passive Biomonitoring .....	211
Sampling and Analytical Procedures for Passive Biomonitoring Using Mosses .....	213
Element Distribution and Content Variability Within Moss Cushions .....	216
Examples of Large-Scale Surveys and Global Monitoring Networks Using Mosses .....	220
Active Monitoring of Airborne Elements with Moss Bags .....	224
Historical Reconstruction of Element Deposition Using Peat Profiles .....	226
Conclusion .....	230
<b>10. Higher Plants as Biomonitors of Airborne Trace Elements .....</b>	<b>237</b>
Introduction .....	237
Element Deposition on Plant Canopies .....	238
Element Accumulation and Cycling in Forest Ecosystems .....	241
Biomonitoring of Element Deposition Using Plant Leaves .....	242
Passive Biomonitoring Using Tree Barks .....	248

	Long-Term Monitoring of Metal Pollution	
	Using Tree Rings .....	252
	Element Accumulation in Stemflow and Throughfall Areas	
	of the Forest Floor .....	255
	Conclusion .....	257
<b>11.</b>	<b>Trace Elements in Terrestrial Food Chains .....</b>	<b>263</b>
	Introduction .....	263
	Effects of Metal Pollution on Soil Invertebrate	
	Communities .....	264
	Effects of Abiotic Stress on Plants and Performance	
	of Herbivorous Insects .....	266
	Herbivorous Vertebrates as Indicators of Metal	
	Pollution .....	267
	Terrestrial Invertebrates as Accumulators of Trace	
	Elements .....	269
	Metal Accumulation in Vertebrate Herbivores .....	277
	The Transfer of Metals Along Terrestrial Food Chains .....	281
	Conclusion .....	285
<b>12.</b>	<b>Phytoremediation of Metal-Contaminated Sites .....</b>	<b>293</b>
	Introduction .....	293
	Impacts of Metals from Mining and Smelting	
	Operations .....	294
	Prevention and Control of Acid Mine Drainage	
	Formation .....	297
	Bioremediation Technologies at Abandoned Mine Sites ....	299
	The Role of Plants in Constructed Wetlands .....	300
	Metal Phytoextraction from Polluted Substrates .....	303
	Health Impacts and Reclamation of Abandoned Mining	
	and Industrial Waste Sites .....	306
	Sustainable In Situ Rehabilitation of Metalliferous	
	Wastes .....	308
	Topsoil Reconstruction .....	308
	Revegetation of Reclaimed Sites .....	310
	Conclusion .....	313