Contents

List of Contributors XXIX

Part I: General Aspects 1

- 1 General Aspects of Biomonitoring Heavy Metals by Plants 3 *R. Wittig*
- 1.1 Introduction 3
- 1.2 Bioindication, Biomonitoring and Closely Related Terms 4
- 1.2.1 Bioindication and Biomonitoring 4
- 1.2.2 Bioaccumulation 9
- 1.3 The Term "Heavy Metals" in the Literature 9
- 1.4 Comparison of Plants with Other Monitoring Systems 11
- 1.5 The Ideal Biomonitor of Heavy Metals in Terrestrial Ecosystems 14
- 1.6 Comparing Different Groups of Plants as Accumulative Bioindicators of Heavy Metals in Terrestrial Ecosystems 15
- 1.6.1 Lichens 15
- 1.6.2 Mosses 16
- 1.6.3 Fungi 18
- 1.6.4 Higher Plants 18
- 1.6.5 Dead Plant Material 20
- 1.6.6 Ecosystem Microsites 21
- 1.7 References 22

Part II: Chemical Aspects 29

2	Chemical Properties of Metals and the Process of Bio-
	accumulation in Terrestrial Plants 31
	B. Streit, W. Stumm
2.1	Monitoring and Bioaccumulation 31
2.2	Periodic Classification of Elements and Chemical
	Behavior 31
2.2.1	Classification of Elements in the Periodic Table 32
2.2.2	A and B Behavior of Metals 33
2.3	Chemical Interactions of Metals in the Environment 35
2.3.1	Major Biogeochemical Reactions of Metals 35

2.3.2 Kinetic Aspects of Chemical Speciation 39

- 2.4 Mobility and Adsorption of Metals in Soils 39
- 2.4.1 General Aspects of Solute Mobility 39
- 2.4.2 The Solid-Water Interface (Surface Reactions) 41
- 2.4.3 Adsorption Isotherms 41
- 2.5 The Root-Mycorrhizal System 42
- 2.5.1 Major Soil Processes 42
- 2.5.2 Uptake Processes by Roots 43
- 2.5.3 Root Influx Barriers to Metal Ions 45
- 2.5.4 Xylem and Phloem Translocation in the Plant 45
- 2.6 Factors and Mechanisms Controlling Bioavailability and Uptake 46
- 2.6.1 Mathematical and Empirical Models 46
- 2.6.2 Bioavailability for Root Uptake 47
- 2.6.3 The Atmospheric-Foliar Uptake Path 48
- 2.6.4 An Overview of Uptake Characteristics of Selected Metals 48
- 2.7 Plant Compartments: Cells and Membranes 51
- 2.7.1 Plant Cell Compartments 51
- 2.7.2 Membranes as Barriers and Transport Mechanisms 52
- 2.8 Biochemical Interactions of Metals in Plants 54
- 2.8.1 The Nature of Biochemical Reaction Partners 54
- 2.8.2 Biochemical Functions and Control Mechanisms of Metal Compounds 55
- 2.8.3 Elimination Mechanisms for Metals 56
- 2.9 Molecular Adaptation and Evolution of Bioaccumulation and Resistance 57
- 2.9.1 Hyperaccumulators 57
- 2.9.2 Genetic Aspects 59
- 2.10 References 60

Part III: Analytical Aspects 63

- 3 Instrumental Analysis of Plants 65 B. Markert
- 3.1 The Individual Analytical Steps and their Influence on the Accuracy and Precision of the Analytical Results 66
- 3.2 Problems and Analytical Planning 68
- 3.3 Representative Sampling of Plant Specimens 70
- 3.3.1 Classification and Examples of Element Concentration Differences and Fluctuations in Plants 72
- 3.3.2 Development of a Sampling Strategy 79
- 3.4 Cleaning and Drying the Sample Material 82

- 3.5 Homogenization, Aliquots, and Storage 84
- 3.6 Decomposition and Ashing 85
- 3.7 Instrumental Measuring Methods 87
- 3.7.1 Precision, Accuracy, and Concentration Dependence of Analytical Data Material 88
- 3.7.2 Comparison of Different Instrumental Measuring Methods 93
- 3.7.2.1 Direct Methods 93
- 3.7.2.2 Composite Methods 95
- 3.8 Data Evaluation 97
- 3.9 References 98

Part IV: Geobotanical and Biogeochemical Prospecting and Analysis for Heavy Metal Deposits 105

- 4 Geobotanical and Biogeochemical Prospecting for Heavy Metal Deposits in Europe and Africa 107 *W. H. O. Ernst*
- 4.1 Introduction 107
- 4.2 Some General Principles of Biogeochemical Prospecting 109
- 4.2.1 The Target Plant Part 113
- 4.2.2 Relationship between Metals in the Environment and in the Plant 113
- 4.3 Geobotanical Prospecting 114
- 4.3.1 The Effect Concentration 115
- 4.3.2 Symptomatic Indicators 116
- 4.3.3 Specific Indicator Plants 117
- 4.3.4 Specific Indicator Vegetation 119
- 4.3.5 Metal Vegetation in Europe 121
- 4.3.6 Metal Vegetation in Africa 123
- 4.4 References 124
- 5 Geobotanical and Biogeochemical Methods for Detecting Mineralization and Pollution from Heavy Metals in Oceania, Asia, and The Americas 127 *R. R. Brooks*
- 5.1 Introduction 127
- 5.2 Biogeochemical Exploration in the Asian Part of the Former Soviet Union 129
- 5.2.1 The Southern Urals 129
- 5.2.2 The Buriat Autonomous Republic 131
- 5.3 Biogeochemical Exploration in the Rest of Asia 134

- 5.3.1 South Asia 134
- 5.3.2 Other Asian Biogeochemical Studies 134
- 5.4 Biogeochemical Exploration in Oceania 135
- 5.4.1 Western Australia 135
- 5.4.2 Eastern Australia 137
- 5.4.3 Tasmania and Northern Territory 138
- 5.4.4 New Zealand 138
- 5.4.5 New Caledonia 138
- 5.5 Biogeochemical Exploration in North America 139
- 5.6 Biogeochemical Exploration in Latin America 142
- 5.7 Geobotany Remote Sensing 143
- 5.8 Geobotany in The Americas 145
- 5.9 Geobotany in Oceania 146
- 5.10 Geobotany in Asia 147
- 5.11 Plants as Indicators of Pollution 148
- 5.12 References 149
- 6 Higher Plants as Indicators for Uranium Occurrence in Soil 155
 - L. Steubing, J. Haneke
 - Summary 155
- 6.1 Introduction 155
- 6.2 Area Description 156
- 6.3 Methods 157
- 6.4 Results 157
- 6.4.1 Element Analyses of Spruce Samples 157
- 6.4.2 Comparison of the Uranium Concentration in Soil and Soil Water 157
- 6.4.3 Uranium Concentration in Plants 159
- 6.4.4 Uranium Transfer from Soil to Plants 162
- 6.5 Discussion 164
- 6.6 References 165
- Plant Distributions and Soil Chemistry at a Serpentine/Non-Serpentine Boundary in California 167
 B. Streit, R. J. Hobbs, S. Streit
- 7.1 The Nature of Ultramafic Rocks 167
- 7.2 Californian Serpentine and Non-Serpentine Mosaics 168
- 7.3 Methods of Analysis 169
- 7.3.1 Sampling Area 169
- 7.3.2 Plant Community Analysis 170
- 7.3.3 Soil and Plant Analysis 170

- 7.4 Metal Concentrations and Plant Communities 171
- 7.4.1 Plant Community Analysis 171
- 7.4.2 Soil Concentrations 173
- 7.4.3 Plant Tissue Concentrations 173
- 7.5 Discussion of the Results 175
- 7.6 References 177
- 8 Serpentine Endemics as Biological Indicators of Soil
 Elemental Concentrations 179
 M. Arianoutsou, P. W. Rundel, W. L. Berry
- 8.1 Introduction 179
- 8.1.1 Serpentine Plants and Soil Mineral Resources 179
- 8.1.2 What are Serpentine Soils? 179
- 8.1.3 Serpentine Soils as Plant Habitats 180
- 8.1.4 Physiology of Serpentine Growth 180
- 8.1.4.1 Mineral Toxicities of Serpentine Soils 180
- 8.1.4.2 Mineral Deficiencies 181
- 8.1.4.3 Calcium/Magnesium Balance 181
- 8.2 California Serpentine Soils 182
- 8.2.1 Distribution and Geological Origin 182
- 8.2.2 Chemical Composition of California Serpentine Soils 183
- 8.3 Nutrient and Trace Metal Accumulation in Serpentine Endemics 185
- 8.3.1 California Serpentine Endemics 185
- 8.3.2 Trace Metal Accumulation in California Serpentine Endemics 186
- 8.4 Conclusions 188
- 8.5 References 188

Part V: Biomonitoring Terrestrial Heavy Metal Pollution by Plants 191

A. Lichens 191

- 9 Lichens as Biomonitors for Heavy Metal Pollution 193 J. Garty
- 9.1 Introduction 193
- 9.2 Lichens as Biomonitors of Lead 195
- 9.2.1 The Use of Lichens as Pb-Biomonitors in Field Studies 195
- 9.2.2 Lichens on Pb-Rich Substrates 205
- 9.2.3 Localization of Pb in the Lichen Thallus 207
- 9.2.4 The Influence of Pb on Lichen Physiology 208

mems	
9.3	Lichens as Biomonitors of Iron 210
9.3.1	Lichens on Fe-Rich Substrates and Relationships between
	Lichens and Fe-Containing Lithic Substrates 210
9.3.2	The Use of Lichens as Fe-Biomonitors in Field Studies 211
9.3.3	Localization of Fe in the Lichen Thallus 212
9.3.4	The Influence of Fe on Lichen Physiology 220
9.4	Lichens as Biomonitors of Copper 223
9.4.1	Lichens on Cu-Rich Substrates 223
9.4.2	The Use of Lichens as Cu-Biomonitors in Field Studies 224
9.4.3	Uptake, Localization, and Toxicity of Cu in Lichens 227
9.5	Lichens as Biomonitors of Zinc 230
9.5.1	Lichens on Zn-Rich Substrates 230
9.5.2	The Use of Lichens as Zn-Biomonitors in Field Studies 231
9.5.3	Uptake, Localization, and Toxicity of Zn in Lichens 233
9.6	Lichens as Biomonitors of Cadmium 237
9.6.1	The Use of Lichens as Cd-Biomonitors in Field Studies 237
9.6.2	Uptake, Localization, and Toxicity of Cd in Lichens 241
9.7	Lichens as Biomonitors of Nickel 243
9.7.1	The Use of Lichens as Ni-Biomonitors in Field Studies 243
9.7.2	Laboratory Experiments on Uptake, Localization, and
	Toxicity of Ni in Lichens 246
9.8	Lichens as Biomonitors of Chromium 248
9.8.1	The Use of Lichens as Cr-Biomonitors in Field Studies 248
9.8.2	Localization of Cr in the Lichen Thallus 252
9.9	Lichens as Biomonitors of Mercury 252
9.9.1	The Use of Lichens as Biomonitors of Hg Emitted from
	Geochemical Sources 252
9.9.2	The Use of Lichens as Biomonitors of Hg Emitted from
	Anthropogenic Sources and in Background Studies 254
9.9.3	Localization of Hg in the Lichen Thallus 257
9.10	References 257
10	Lichens as Bioindicators of Heavy Metal Pollution: A Case
	Study at La Spezia (N Italy) 265
	P. L. Nimis, M. Castello, M. Perotti
10.1	Introduction 265
10.2	Survey Area, Data, and Methods 268
10.3	Results 271

- 10.4 Conclusions 283
- 10.5 References 284

Ko

11 Multi-Residue Analysis with Passive Biomonitoring: A New Approach for Volatile Multi-Element Contents, Heavy Metals and Polycyclic Aromatic Hydrocarbons with Lichens in Switzerland and the Principality of Liechtenstein 285 *R. Herzig*

Summary 285

- 11.1 Introduction 285
- 11.2 Material and Methods 287
- 11.2.1 Sampling Sites in the Principality of Liechtenstein and the City of Berne 287
- 11.2.2 Sample-Taking and Random Sample Concept 287
- 11.2.3 Chemical Trace Analysis 290
- 11.2.3.1 Inorganic Multi-Element Analysis 290
- 11.2.3.2 Organic Trace Analyses 291
- 11.3 Results and Discussion 293
- 11.3.1 Multi-Element Pollution at the Study Sites 293
- 11.3.1.1 Structure and Preparation of the Station Charts 293
- 11.3.1.2 Characterization of the Study Sites by Means of Station Charts 297
- 11.3.2 Comparison of the Multi-Element Pollution in the Principality of Liechtenstein with Other Areas in Switzerland 302
- 11.3.2.1 Multi-Factorial Comparison of Total Immission Load, Single Element Load, and Heavy Metal Load Index 305
- 11.3.3 Spatial Distribution of the Single Elements 306
- 11.3.3.1 General Immission Load Elements 307
- 11.3.3.2 Pollution Elements of Single Emittents 307
- 11.3.4 Multi-Element Pollution Profile 310
- 11.3.5 Immission-Ecological Relevance of the Multi-Element Analyses 313
- 11.3.5.1 Multi-Element Concentrations and Total Air Pollution Classes in the Principality of Liechtenstein and the City of Berne 314
- 11.3.6 Dependency of Multi-Element Pollution Load on Utilization Type 318
- 11.3.6.1 Settlement Type 318
- 11.3.7 Organic Pollutant Analyses 323
- 11.3.7.1 Polycyclic Aromatic Hydrocarbons (PAH) 323
- 11.3.7.2 Polycyclic Aromatic Hydrocarbons in Lichens 323
- 11.3.7.3 Reproducibility of the PAH Analyses 326
- 11.4 Conclusions 326
- 11.5 References 327

XX Contents

- Bioindication of Road Motor Traffic Caused Heavy Metal Pollution by Lichen Transplants 329
 Z. Tuba, Z. Csintalan Summary 329
- 12.1 Introduction 329
- 12.2 Materials and Methods 331
- 12.2.1 The Study Area 331
- 12.2.2 Cryptogam Plant Species Used for Bioindication 332
- 12.2.3 Cryptogam Transplantation Technique 332
- 12.2.4 The Control Site 332
- 12.2.5 Application of the Transplantation Method along Main Road No. 6 333
- 12.2.6 Time Schedule of the Study 333
- 12.2.7 Element Analysis 333
- 12.3 Results 334
- 12.3.1 Monitoring the Distance-Dependent Concentrations of (Heavy) Metals 334
- 12.4 Discussion 339
- 12.5 References 340

B. Fungi 343

- 13 Monitoring of Heavy Metals in Soils by Higher Fungi 345 *I. Wondratschek, U. Röder*
- 13.1 Introduction 345
- 13.2 Fungi as Bioindicators 346
- 13.2.1 Reaction-Indication 346
- 13.2.2 Accumulation-Indication 347
- 13.2.2.1 Mercury 350
- 13.2.2.2 Cadmium 352
- 13.2.2.3 Lead 353
- 13.2.2.4 Zinc 354
- 13.2.2.5 Copper 355
- 13.3 Factors Influencing the Heavy Metal Content of Fungi 356
- 13.4 Conclusions 359
- 13.5 References 360
- Applicability of Fungi to the Monitoring of Environmental Pollution by Heavy Metals 365
 V. Mejstřik, A. Lepšová
- 14.1 Principle and Mechanism 365
- 14.2 Bioaccumulation 366
- 14.2.1 Cadmium 367

- 14.2.2 Mercury 369
- 14.2.3 Lead 369
- 14.2.4 Copper 371
- 14.2.5 Arsenic 374
- 14.2.6 Zinc 374
- 14.2.7 Selenium 375
- 14.2.8 Manganese, Nickel, Cobalt 375
- 14.3 References 376

C. Mosses 379

- 15 Some Aspects of Biomonitoring of Air Pollutants Using Mosses, as Illustrated by the 1976 Norwegian Survey 381 *E. Steinnes*
- 15.1 Introduction 381
- 15.2 Materials and Methods 382
- 15.2.1 Selection of Species 382
- 15.2.2 Sampling 382
- 15.2.3 Analysis 383
- 15.3 Comparison of the 1976 Survey (43 Samples) and the 1977 Survey (490 Samples) Based on *Hylocomium splendens* 383
- 15.4 Relative Efficiencies of Different Moss and Lichen Taxa to Retain Airborne Trace Elements 389
- 15.5 References 394
- Mosses as Biomonitors of Heavy Metal Contamination within Urban Areas 395
 F. Brüning, K. H. Kreeb Summary 395
- 16.1 Introduction 395
- 16.2 Materials and Methods 396
- 16.3 Results and Discussion 397
- 16.3.1 Range of Heavy Metal Concentrations 397
- 16.3.2 Determination of Local Differences of Heavy Metal Immissions 399
- 16.3.3 Comparison of Heavy Metal Accumulation in Different Species 399
- 16.3.4 Comparison of Active and Passive Monitoring 401
- 16.4 References 401
- 17 The Use of Moss Transplantation Technique for Bioindication of Heavy Metal Pollution 403 Z. Tuba, Z. Csintalan

Summary 403

- 17.1 Introduction 403
- Materials and Methods 404 17.2
- The Study Area 404 17.2.1
- Cryptogam Plant Species Used for Bioindication 17.2.2 405
- Cryptogam Transplantation Technique 406 17.2.3
- The Control Site 406 17.2.4
- Application of the Transplantation Method in Százhalom-17.2.5 batta and its Environs 406
- 17.2.6 Time Schedule of the Study 406
- 17.2.7 Element Analysis 406
- 17.3 Results 406
- 17.3.1 Spatial Distribution of Heavy Metals in the Study Area 406
- Discussion 17.4 408
- 17.5 References 411

D. Higher Plants 413

- 18 The Effects of Heavy Metal Stress on Higher Plants and their Use as Biomonitors 415 J. A. C. Verkleij
- 18.1 Introduction 415
- 18.2 Long-Term Exposure to Naturally Occurring Metal Stress 416
- 18.3 Long-Term Exposure to Man-Made Metal Stress 417
- 18.4 Short-Term Exposure to Man-Made Metal Stress 418
- 18.5 Effect Parameters in Metal Toxicity Tests 419
- 18.5.1 Root Elongation Method 419
- 18.5.2 Other Life History Characteristics 421
- Physiological Parameters (Biomarkers) 422 18.5.3
- 18.6 References 423
- 19 Large-Scale Screening of Heavy Metal Burdens in Higher Plants 425 G. Wagner
- 19.1 Introduction: Why is Large-Scale Screening Necessary? 425
- 19.1.1 Spatial Patterns of Heavy Metal Pollution 425
- Heavy Metal Accumulation in Plants 19.1.2 426
- 19.1.3 Large-Scale Screening by Bioindication Methods 426
- 19.2 Criteria and Recommendations for the Selection and Standardization of Suitable Bioindicator Systems 426
- 19.2.1 Standardization 428
- 19.2.2 Sampling Guideline 428

XXII

£.

- 19.2.3 Standardized Poplar Leaf Samples as an Example for a Bioindicator System Especially Suitable for Large-Scale Screenings 429
- 19.3 Design of Sampling Grids 430
- 19.3.1 Design of Regular Sampling Grids for Extensive Background Monitoring 432
- 19.3.2 Design of Emittent-Related Sampling Grids 433
- 19.4 Data Evaluation by Geostatistical Methods 433
- 19.5 References 433
- Monitoring of Heavy Metal Pollution by *Taraxacum officinale* 435
 R. Djingova, I. Kuleff
- 20.1 Introduction 435
- 20.2 Materials and Methods of Analysis 436
- 20.2.1 Sampling, Sample Preparation, Investigated Region 436
- 20.2.2 Methods of Analysis 437
- 20.2.2.1 Instrumental Neutron Activation Analysis 437
- 20.2.2.2 Atomic Absorption Spectrometry 437
- 20.2.2.3 Mathematical Methods for Evaluation 437
- 20.3 Accumulation of Heavy and Toxic Elements in Different Microspecies of *Taraxacum officinale* 437
- 20.4 Background Concentrations of the Elements Determined in *Taraxacum officinale* 442
- 20.5 Comparison of the Ability of Several Vascular Plants to Respond to Environmental Pollution 445
- 20.6 Is there any Proportionality between Heavy Metal Pollution and the Response of *Taraxacum officinale*? 448
- 20.7 Monitoring of Heavy Metal Pollution by *Taraxacum officinale* 451
- 20.7.1 Evaluation of Local Industrial Pollution 451
- 20.7.2 Comparative Study of Urban Pollution Using *Taraxacum* officinale 453
- 20.7.3 Investigation of Roadside Pollution by *Taraxacum officinale* 455
- 20.8 Conclusions 456
- 20.9 References 457
- Plant Leaves and Lichens as Biomonitors of Natural or Anthropogenic Emissions of Mercury 461
 R. Bargagli
- 21.1 Introduction 461

- 21.2 Methodologies 463
- 21.2.1 Total Gaseous Mercury 463
- 21.2.2 Mercury in Plant Leaves 464
- 21.2.3 Epiphytic Lichens for Monitoring Atmospheric Mercury 467
- 21.3 Biomonitoring of Mercury Emission and Deposition 470
- 21.3.1 Pine Needles as Monitors of Atmospheric Mercury in the Mediterranean Region 470
- 21.3.2 Epiphytic Lichens as Biomonitors Atmospheric Mercury 467
- 21.4 Concluding Remarks 480
- 21.5 References 481
- Trace Metals in Legumes and Monocotyledons and their Suitability for the Assessment of Soil Contamination 485
 A. Kabata-Pendias, M. Piotrowska, S. Dudka Summary 485
- 22.1 Introduction 485
- 22.2 Plants from Arable Soils 486
- 22.3 Plants from Soils Amended with Various Wastes 491
- 22.4 References 494
- Heavy Metal Accumulation by Ruderal and Cultivated
 Plants in a Heavily Polluted District of Budapest 495
 M. Kovács, G. Turcsányi, K. Penksza, L. Kaszab, P. Szőke
- 23.1 Introduction 495
- 23.2 Material and Methods 496
- 23.3 Results 497
- 23.4 Discussion 500
- 23.5 References 505
- 24 Heavy Metals in the Vegetation as Indicators for the Environmental Pollution in the Area of the Former USSR 507 *F. Ya. Rovinsky, L. V. Burtseva, T. B. Chicheva*
- 24.1 Introduction 507
- 24.2 Observational Methodology 507
- 24.3 Background Heavy Metal Pollution of the Regional Atmosphere and Soils 508
- 24.4 Background Vegetation Pollution by Heavy Metals 509
- 24.5 Conclusions 513
- 24.6 References 513
- 25 Heavy Metal Accumulation by Plants Growing alongside the Motor Roads: A Case Study from Turkey 515 *M. A. Ötztürk, I. Türkan*

- 25.1 Introduction 515
- 25.2 Case Studies 516
- 25.2.1 Metal Accumulation in Relation to Distance from the Road 516
- 25.2.2 Metal Accumulation in Relation to Traffic Intensity 517
- 25.2.3 Metal Accumulation in Relation to Plant Morphology 518
- 25.2.4 Biomonitoring of Metals with Bark Samples 520
- 25.2.5 Rinsing of Metals from Plant Parts 521
- 25.3 Conclusions 521
- 25.4 References 522
- 26 Passive Monitoring of Airborne Pollutants, Particularly Trace Metals, with Tree Bark 523 A. Walkenhorst, J. Hagemeyer, S. W. Breckle
- 26.1 Introduction 523
- 26.1.1 Basic Principles and Aims of Air Pollution Biomonitoring with Tree Bark 523
- 26.1.2 History of the Use of Tree Bark as a Medium of Bioindication – a Survey 525
- 26.2 Trace Metals in Tree Bark 526
- 26.2.1 Investigations Dealing with Levels of Trace Elements in Tree Bark – a Selection of General Studies 526
- 26.2.2 Concentrations of Trace Metals in Bark of Trees along Roads – Pb as an Indicator of Automobile Exhaust Fumes 527
- 26.2.3 Monitoring of Air Pollution in Urban and Industrialized Areas 529
- 26.3 Advantages and Limitations of Biomonitoring with Tree Bark 532
- 26.3.1 Advantages 532
- 26.3.2 Problems 533
- 26.3.2.1 Biotic Influences (External and Internal) 533
- 26.3.2.2 Abiotic Problems 534
- 26.3.2.3 Importance of Standardization 534
- 26.4 Conclusions 535
- 26.5 Recommendations for Future Research 537
- 26.6 References 538
- 27 Monitoring Trace Metal Pollution with Tree Rings: A Critical Reassessment 541 J. Hagemeyer
- 27.1 Introduction and Basic Concepts 541
- 27.2 First Attempts 543

- 27.3 Literature Review of Dendroanalytical Studies 544
- 27.3.1 Studies with Results Supporting the Concept of Dendroanalysis 545
- 27.3.2 Studies Questioning the Method of Dendroanalysis 552
- 27.4 Conclusions and Remarks 556
- 27.5 Open Questions What Can Be Done? 560
- 27.6 References 561

Part VI: Analysis of Heavy Metals in Plants for the Selection of Future Monitoring Species 565

- 28 Do Phytopathogenic Arthropods Alter Metal Levels of Bioindicator Plants 567
 T. Reijonen, P. Nuorteva
- 28.1 Introduction 567
- 28.2 Massive Galls of Pemphigid Aphids 567
- 28.3 Less Massive Galls of Pemphigid Aphids 569
- 28.4 Small Galls of Eriophyid Mites 569
- 28.5 Leaf Mines Caused by *Eriocrania* Moths 571
- 28.6 Crowns Damaged by *Cephalcia abietis* Larvae 572
- 28.7 Brink Gnawing by the Curculionid Polydrosus pictus 572
- 28.8 Plant Damage and Honeydew Produced by Homoptera 573
- 28.9 Conclusions 575
- 28.10 References 576
- Seasonal Variations of Foliar Metal Content in Three Fruit Tree Species 577
 M. Deu, K. H. Kreeb Summary 577
- 29.1 Introduction 577
- 29.2 Methods 578
- 29.3 Results and Discussion 579
- 29.3.1 Washing Procedures 579
- 29.3.2 Seasonal Changes in Metal Contents during the 1988 Growing Season 582
- 29.3.2.1 Lead 582
- 29.3.2.2 Manganese 583
- 29.3.2.3 Iron 584
- 29.3.2.4 Copper 584
- 29.3.2.5 Zinc 586
- 29.3.3 Features of Metal Retention 587
- 29.3.4 Conclusions 590
- 29.4 References 591

- Changes in Cadmium Concentration in the Xylem Sap of *Fagus sylvatica* L. with Increasing Altitude 593
 R. Heimerich Summary 593
 - Jummary 595
- 30.1 Introduction 593
- 30.2 Material and Methods 593
- 30.3 Results 594
- 30.4 Discussion 599
- 30.5 Conclusions 600
- 30.6 References 600
- Effects of Altitude on Heavy Metal Accumulation in Soils of Beech Forest Ecosystems 601
 H. Jochheim, V. Glavac, H. Koenies, R. Heimerich
- 31.1 Introduction 601
- 31.2 Materials and Methods 602
- 31.2.1 Locations of Investigation 602
- 31.2.2 Soil Sampling 603
- 31.2.3 Chemical Analyses 603
- 31.2.4 Process Used to Eliminate the Influence of the Humus Content 603
- 31.3 Results 604
- 31.4 Discussion 609
- 31.5 References 611
- 32 Concentrations of Selected Heavy Metals in Different Compartments of a Mountain Rain Forest Ecosystem in Sri Lanka 613
 R. Jayasekera
 - Summary 613
- 32.1 Introduction 613
- 32.2 The Study Site and Methods 614
- 32.3 Results 615
- 32.4 Discussion 621
- 32.5 References 622
- **Index** 623