

SAMPLING FOR RADIONUCLIDES IN THE ENVIRONMENT

CONTENTS

PREFACE	1
GLOSSARY	3
ABSTRACT	9
EXECUTIVE SUMMARY	11
1 INTRODUCTION	13
2 VARIABILITY OF ENVIRONMENTAL RADIOACTIVITY AND RADIATION	15
2.1 Causes of variation	15
2.2 Typical magnitudes of variation	17
2.2.1 Soils	17
2.2.2 Terrestrial vegetation	19
2.2.3 Terrestrial animal tissues	21
2.2.4 Components of aquatic ecosystems	22
2.2.5 Background radiation	23
3 GENERAL SAMPLING CONCEPTS AND PRINCIPLES	25
3.1 Introduction	25
3.1.1 Objectives	26
3.1.2 Environmental context	26
3.1.3 Inferences and populations	27
3.1.4 Representativeness	28
3.1.5 Overall sampling approach	29
3.2 Methods of sampling	29
3.2.1 Introduction	29
3.2.2 Sampling designs	29
3.2.2.1 Judgmental sampling	29
3.2.2.2 Simple random sampling	29
3.2.2.3 Two-stage sampling	29
3.2.2.4 Stratified sampling	30
3.2.2.5 Systematic sampling	30
3.2.2.6 Cluster sampling	31
3.2.2.7 Double sampling	31
3.3 Number of replicate samples	31
3.4 Sample mass or volume	32
3.5 Compositing and pooling	32

CONTENTS

3.6	Practical sampling issues	33
3.7	Data analysis	33
3.7.1	<i>Below-detection-limit observations</i>	34
3.8	Quality assurance	34
4	ESTIMATING STATISTICAL QUANTITIES: MEAN, TOTAL, PROPORTION, PERCENTILE, AND RATIO	35
4.1	Introduction	35
4.2	Population mean and total	35
4.2.1	<i>Introduction</i>	35
4.2.2	<i>Simple random sampling in practice</i>	36
4.2.2.1	<i>Estimation of the average baseline ^{14}C level in vegetation</i>	36
4.2.3	<i>Example: ^{137}Cs contained activity (inventory) in sediment of an estuary</i>	39
4.2.4	<i>Systematic sampling</i>	41
4.3	Proportion	43
4.3.1	<i>Introduction</i>	43
4.3.2	<i>Simple random sampling</i>	43
4.3.3	<i>Stratified sampling for proportions</i>	44
4.4	Estimation of a percentile	44
4.5	Ratios	45
4.5.1	<i>General principles</i>	45
4.5.2	<i>Sampling considerations</i>	45
4.5.3	<i>Comparison of unpaired and paired sampling</i>	46
4.5.4	<i>Examples</i>	46
4.5.5	<i>Other considerations</i>	46
4.6	Other sampling schemes	47
4.6.1	<i>Two-stage sampling</i>	47
4.6.2	<i>Double sampling</i>	47
4.6.3	<i>Quadrat and line-transect sampling</i>	48
4.7	General comments	48
5	SAMPLING TO ESTIMATE SPATIAL PATTERN	49
5.1	Introduction	49
5.1.1	<i>Spatial structure: general comments</i>	49
5.1.2	<i>Sampling objectives</i>	50
5.1.3	<i>The sampling approach of Section 3 applied to spatial data</i>	51
5.2	Examples of the sampling approach	51
5.2.1	<i>Mapping plutonium distribution over a region</i>	51
5.2.2	<i>Mapping using spatially integrated data</i>	51
5.2.3	<i>Estimating the scale of spatial variability</i>	52
5.2.4	<i>Identifying vulnerable land areas</i>	52
5.3	Terminology and notation	53
5.3.1	<i>Spatial random process</i>	53
5.3.2	<i>Spatial trend</i>	53
5.3.3	<i>Periodicity</i>	53
5.3.4	<i>Spatial covariance</i>	53
5.3.5	<i>Isotropy and anisotropy</i>	53
5.3.6	<i>Stationarity</i>	53
5.3.7	<i>Relationship between the semivariogram and the spatial correlation</i>	54
5.3.8	<i>Empirical variogram</i>	54
5.3.9	<i>Modeling the empirical variogram</i>	54
5.4	Design- and model-based sampling methods	55

5.5	Design-based sampling schemes for spatial data	56
5.5.1	<i>Random and stratified random sampling</i>	56
5.5.2	<i>Systematic grid sampling and geometric grid pattern</i>	56
5.5.3	<i>Transect sampling</i>	57
5.5.4	<i>Cluster sampling</i>	57
5.5.5	<i>Number of samples required</i>	58
5.6	Spatial interpolation and prediction	58
5.6.1	<i>Non-stochastic interpolation methods</i>	58
5.6.2	<i>Trend surfaces</i>	58
5.6.3	<i>Geostatistical methods for spatial analysis and sampling</i>	58
5.6.4	<i>Describing the small-scale spatial variation and measurement error</i>	59
5.6.5	<i>Predicting the spatial process at unobserved point locations: kriging</i>	60
5.6.6	<i>Predicting values for areas larger than the sample size: block kriging</i>	61
5.6.7	<i>Other kriging methods: indicator kriging and co-kriging</i>	61
5.6.8	<i>Use of the variogram to design a sampling strategy</i>	61
5.6.9	<i>Number of samples required</i>	61
5.6.10	<i>Difficulties</i>	61
5.6.11	<i>Examples of model-based analyses</i>	62
5.6.12	<i>Prior knowledge and pilot studies</i>	62
5.7	Locating hot spots	63
5.7.1	<i>Probability of detecting a hot spot of a specified size</i>	63
5.7.2	<i>Estimating the probability that a hot spot exists when one is not detected</i>	63
5.7.3	<i>Delineating the edges of a hot spot</i>	64
5.7.4	<i>Detecting hot particles</i>	64
5.8	Conclusions	64
6	TEMPORAL AND SPATIO-TEMPORAL SAMPLING PROBLEMS	65
6.1	Introduction	65
6.1.1	<i>Types of studies with temporal or spatio-temporal sampling</i>	65
6.1.2	<i>Time-series data</i>	66
6.1.3	<i>Trend in a time series</i>	66
6.1.4	<i>Periodicity in a time series</i>	67
6.1.5	<i>Example of trend, seasonal, and random components of variation</i>	67
6.2	Sampling issues and designs to assess temporal trends	67
6.2.1	<i>Choice of sampling times</i>	68
6.2.2	<i>Choice of sampling units</i>	69
6.2.3	<i>Designs that combine independent and repeated sampling</i>	70
6.2.4	<i>Other practical issues</i>	70
6.3	Sampling issues and designs to detect impact	71
6.3.1	<i>Before-After-Control-Impact assessment designs and extensions</i>	72
6.4	Network design	72
6.5	Examples of sampling to describe trends	72
6.5.1	<i>Sampling fish from a lake</i>	73
6.5.2	<i>Food-chain monitoring</i>	73
6.5.3	<i>Trend and seasonality of ^{14}C in seaweed, and variation in outdoor radon</i>	73
6.5.4	<i>Whole-body monitoring</i>	74
6.5.5	<i>Long-term trend of radiocesium in milk after Chernobyl</i>	74
6.5.6	<i>Long-term temporal dependence of ^7Be deposition</i>	75
6.6	Examples of sampling for impact assessment	75
6.6.1	<i>Monitoring of a nuclear power station</i>	75
6.6.2	<i>Post-release trends of contamination levels</i>	76
6.7	General comments about examples and conclusions	76

7	GENERAL SUMMARY	77
7.1	Variation	77
7.2	The meaning of statistical sampling	77
7.3	The environmental context	77
7.4	Representativeness	78
7.5	Steps in developing a sampling design	78
7.6	Sampling approaches	78
7.6.1	<i>Judgmental sampling</i>	78
7.6.2	<i>Simple random sampling</i>	78
7.6.3	<i>Stratified sampling</i>	78
7.6.4	<i>Systematic sampling</i>	79
7.6.5	<i>Other sampling designs</i>	79
7.7	Calculation of statistical quantities	79
7.8	Spatial and temporal context of environmental sampling	79
7.9	Spatial sampling	79
7.10	Temporal sampling	80
7.11	Final comments	80
	REFERENCES	81
	APPENDIX A 10,000 RANDOM DIGITS	85
	APPENDIX B UPPER CRITICAL VALUES OF THE STUDENT'S t DISTRIBUTION	89
	QUANTITIES AND SYMBOLS USED IN THIS REPORT	91