CONTENTS

Prologue v

Contents vii

List of Figures xiii

List of Tables xv

Acknowledgments xvii

PART ONE: THEORETICAL BACKGROUND

1. INTRODUCTION TO MORPHOMETRICS 1

1.1. INTRODUCTION 1

1.1.1. The Visual Process 2

1.1.2. A Dual View of the World 3

1.2. THE ISSUE OF QUANTIFICATION 5

1.2.1. What is Morphometrics? 7

1.2.2. From Morphology to Process 9

1.3. CONTENTS OF THIS VOLUME 11

1.4. A NOTE TO THE READER 11

KEY POINTS OF THE CHAPTER 13

CHECK YOUR UNDERSTANDING 13

REFERENCES CITED 13

2. AN INTRODUCTION TO RESEARCH METHODS 17

2.1. INTRODUCTION 17

2.1.1. Definitions of Science 18

2.1.2. The Scientific Method 19

2.2. LIMITATIONS OF SCIENCE 20

2.2.1. Ethical Considerations 20

2.2.2. Principle of Independence 22

2.3. SOME STATISTICAL CONSIDERATIONS 23

2.3.1. Bias toward the Use of Statistics 24

2.3.2. Types of Research Studies *24*

2.4. THE RESEARCH PLAN 25
2.4.1. Initial Steps *25*
2.4.2. Collection and Data Analysis *26*
2.4.3. Some Other Requirements *27*

2.5. THE PROCEDURAL ENDEAVOR 27
2.5.1. From the Literature Search to Hypotheses *28*
2.5.2. The Research Design *32*
2.5.3. Research Results *35*

2.6. THE DOCUMENTATION ENDEAVOR 36
2.6.1. Introductory Material *37*
2.6.2. Materials and Methods *38*
2.6.3. Results and Conclusions *39*

2.7. SOME FINAL COMMENTS 40

KEY POINTS OF THE CHAPTER 41

CHECK YOUR UNDERSTANDING 41

REFERENCES CITED 42

3. A HISTORY OF SCIENTIFIC MEASUREMENT 45

3.1. INTRODUCTION 45
3.1.1. Precursors of Science *46*
3.1.2. Development of Language *47*

3.2. EARLY BEGINNINGS OF MEASUREMENT 48
3.2.1. The First Civilization: Mesopotamia *50*
3.2.2. Egyptian, Roman and Later Accomplishments *51*
3.2.3. Developments on the Indian Subcontinent *52*
3.2.4. Rise of Chinese Civilization *53*

3.3. GREEK AND ROMAN SCIENCE 53
3.3.1. The Pre-Socratics *54*
3.3.2. From Pythagoras to Democritus *55*
3.3.3. Platonic and Aristotelian Philosophy *58*
3.3.4. Greco-Roman Achievements *62*

3.4. THE HELLENISTIC PERIOD INTO MEDIEVALISM 65
3.4.1. The Islamic Contribution *66*
3.4.2. Early Medieval Philosophical Developments *68*
3.4.3 The Ptolemaic Worldview *68*

3.5. FROM THE RENAISSANCE TO THE ENLIGHTENMENT 69
3.5.1. The Copernican Revolution *69*
3.5.2. Developments Leading to Newton and Beyond *75*

KEY POINTS OF THE CHAPTER 81

CHECK YOUR UNDERSTANDING 81

REFERENCES CITED 82

4. TOWARD QUANTIFICATION IN BIOLOGY 85

4.1. INTRODUCTION 85
4.1.1. Classification of Organisms 86
4.1.2. The Influence of Embryology on Heredity 88

4.2. BEGINNINGS OF QUANTIFICATION IN BIOLOGY 89
4.2.1. The Rise of Classical Genetics 90
4.2.2. The Roots of Statistical Theory 91
4.2.3. The Controversy over Biological Variation 92
4.2.4. The Evolutionary Synthesis 96

4.3. THE QUANTITATIVE STUDY OF FORM 99
4.3.1. Early Developments in the Study of Morphology 100
4.3.2. From Morphology to Morphometrics 101

KEY POINTS OF THE CHAPTER 102

CHECK YOUR UNDERSTANDING 103

REFERENCES CITED 103

5. COMPLEXITY, SYSTEMS AND MODELS 107

5.1. INTRODUCTION 107

5.2. COMPLEXITY 109
5.2.1. Complex Adaptive Systems 111
5.2.2. Properties of Emergence and Self-Organization 114
5.2.3. Morphogenesis and Complexity 116

5.3. SYSTEMS THEORY 117
5.3.1. Systems Applications in Biology 118
5.3.2. The Systems Approach 118

5.4. THE DEVELOPMENT OF MODELS 119
5.4.1. Model Building 120
5.4.2. Types of Models 121
5.4.3. Modeling: A Simple Example 122
5.4.4. Other Approaches to Modeling 126
5.4.5. The Challenge: Modeling the Development of Form 128

KEY POINTS OF THE CHAPTER 131

CHECK YOUR UNDERSTANDING 131

REFERENCES CITED 132

6. A FORMAL MODEL OF FORM 135

6.1. INTRODUCTION 135

6.2. A HEURISTIC MODEL OF FORM 135
6.2.1. Justification for Quantitative Models of Form *135*
6.2.2. Developing a Concept of Form *136*

6.3. REPRESENTATIONS OF FORM 137
6.3.1. Specific Properties of Form *137*
6.3.2. Size, Shape and Structural Considerations *139*
6.3.3. A More Realistic Model of Form *141*
6.3.4. A Dynamic Model of Form *143*

6.4. MORPHOMETRIC PROCEDURES 146

KEY POINTS OF THE CHAPTER 149

CHECK YOUR UNDERSTANDING 149

REFERENCES CITED 150

PART TWO: MORPHOMETRIC TECHNIQUES

7. MULTIVARIATE MORPHOMETRICS 155

7.1. INTRODUCTION 155
7.1.1. Historical Background *155*
7.1.2. Multivariate Procedures *156*
7.1.3. Eigenvalues and Eigenvectors *158*

7.2. DIFFERENCES BETWEEN GROUPS 159
7.2.1. Discriminant Functions *159*
7.2.2. Mahalanobis D^2 Statistic *160*
7.2.3. Canonical Variate Analysis *161*
7.2.4. Cluster Analysis *164*

7.3. DIFFERENCES WITHIN GROUPS 164
7.3.1. Factor Analysis *164*
7.3.2. Principal Components Analysis *166*

7.4. SOME FINAL COMMENTS 167

KEY POINTS OF THE CHAPTER 167

CHECK YOUR UNDERSTANDING 167

REFERENCES CITED 168

8. COORDINATE MORPHOMETRICS 173

8.1. INTRODUCTION 173

8.2. THE CONVENTIONAL METRICAL APPROACH 173
8.2.1. The Issue of Point Homology *173*

8.2.2. The Conventional Method (CMA) ... *175*
8.2.3. Use of Angles and Ratios as Shape Measures ... *175*
8.2.4. Some Other Deficiencies with CMA ... *178*

8.3. BIORTHOGONAL GRIDS ... 179
8.3.1. Basis for Biorthogonal Grids ... *179*
8.3.2. Constraints of Biorthogonal Grids ... *180*

8.4. FINITE ELEMENT ANALYSIS ... 181
8.4.1. Finite Elements in 2-D ... *182*
8.4.2. Finite Elements in 3-D ... *183*

8.5. THIN PLATE SPLINES ... 184
8.5.1. The Interpolation Function ... *184*
8.5.2. Visualization of the Thin Plate Spline ... *184*

8.6. EUCLIDEAN DISTANCE MATRIX ANALYSIS ... 186

KEY POINTS OF THE CHAPTER ... 187

CHECK YOUR UNDERSTANDING ... 187

REFERENCES CITED ... 188

9. BOUNDARY MORPHOMETRICS ... 191

9.1. INTRODUCTION ... 191

9.2. MEDIAN AXIS TECHNIQUES ... 192
9.2.1. Definition of the Median Axis ... *192*
9.2.2. Variations on a Theme ... *193*

9.3. CONVENTIONAL FOURIER DESCRIPTORS ... 196
9.3.1. Frequency, Amplitude and Phase Relationships ... *196*
9.3.2. Fourier's Series ... *197*
9.3.3. Fourier's Series as Discrete Approximations ... *198*
9.3.4. Residuals, Positional-Orientation and Size-Standardization ... *200*
9.3.5. Applications Using FDs ... *202*

9.4. EIGENSHAPE ANALYSIS ... 206
9.4.1. Algorithm for Eigenshape Analysis ... *206*
9.4.2. Procedures Involved in Eigenshape Analysis ... *206*

9.5. ELLIPTICAL FOURIER FUNCTIONS ... 209
9.5.1. The Kuhl and Giardina Parametric Formulas ... *210*
9.5.2. Amplitude, Power and Phase Relationships ... *211*
9.5.3. Other Elliptical Fourier Function Parameters ... *212*
9.5.4. Positional-Orientation and Size-Standardization Revisited ... *212*
9.5.5. Homology Once More ... *212*
9.5.6. Applications Using EFFs ... *214*

9.6. FOURIER TRANSFORMS ... 217

9.6.1 The Discrete Fourier Transform *217*
9.6.2. The Fast Fourier Transform *220*
9.6.3. The Short Time Fourier Transform *221*

9.7. WAVELET ANALYSIS 222
9.7.1. The Continuous Wavelet Transform *222*
9.7.2. The Discrete Wavelet Transform *223*
9.7.3. One-Dimensional Wavelet Applications *225*

KEY POINTS OF THE CHAPTER 226

CHECK YOUR UNDERSTANDING 226

REFERENCES CITED 227

10. STRUCTURAL MORPHOMETRICS 235

10.1. INTRODUCTION 235

10.2. THE FOURIER TRANSFORM REVISITED 236

10.3. OPTICAL DATA ANALYSIS 236
10.3.1. The One-Dimensional Optical Power Spectrum *236*
10.3.2. The Two-Dimensional Optical Power Spectrum *237*
10.3.3. Two-Dimensional Optical FT Applications *238*

10.4. TWO-DIMENSIONAL WAVELETS 240
10.4.1. Wavelet Analysis of Two-Dimensional Images *240*
10.4.2. Two-Dimensional Wavelet Applications *242*

KEY POINTS OF THE CHAPTER 244

CHECK YOUR UNDERSTANDING 244

REFERENCES CITED 245

EPILOGUE 247

REFERENCES CITED 248

APPENDIX I. EFF23: A COMPUTER PROGRAM 249

A.1.1. INTRODUCTION 249

A.1.2. BRIEF OVERVIEW OF EFF23 249

APPENDIX II. EFF23 PROGRAM FLOWCHARTS 250

INDEX 253