Statistics for Terrified Biologists

Helmut F. van Emden
Emeritus Professor of Horticulture
School of Biological Sciences
University of Reading, UK

Blackwell
Publishing

Contents

Preface **xiii**

1 How to use this book **1**
Introduction 1
The text of the chapters 1
What should you do if you run into trouble? 2
Elephants 3
The numerical examples in the text 3
Boxes 3
Spare-time activities 4
Executive summaries 4
Why go to all that bother? 4
The bibliography 6

2 Introduction **8**
What are statistics? 8
Notation 8
Notation for calculating the mean 10

3 Summarizing variation **12**
Introduction 12
Different summaries of variation 13
Range 13
Total deviation 13
Mean deviation 13
Variance 14
Why $n - 1$? 16
Why the squared deviations? 17
The standard deviation 18
The next chapter 20
Spare-time activities 20

4 When are sums of squares NOT sums of squares? 21
Introduction 21
Calculating machines offer a quicker method of calculating sums of squares 21
Added squares 21
The correction factor 22
Avoid being confused by the term "sum of squares" 22
Summary of the calculator method of calculating down to standard deviation 23
Spare-time activities 24

5 The normal distribution 25
Introduction 25
Frequency distributions 25
The normal distribution 26
What per cent is a standard deviation worth? 27
Are the percentages always the same as these? 29
Other similar scales in everyday life 30
The standard deviation as an estimate of the frequency of a number occurring in a sample 31
From per cent to probability 31
Executive summary 1 – The standard deviation 33

6 The relevance of the normal distribution to biological data 35
To recap 35
Is our observed distribution normal? 36
Checking for normality 37
What can we do about a distribution that clearly is not normal? 38
Transformation 38
Grouping samples 40
Doing nothing! 40
How many samples are needed? 40
Factors affecting how many samples we should take 41
Calculating how many samples are needed 41

7 Further calculations from the normal distribution 42
Introduction 42
Is "A" bigger than "B"? 42
The yardstick for deciding 43
Derivation of the standard error of a difference between two means 45
Step 1 – from variance of single data to variance of means 45

Step 2 – from variance of single data to "variance of differences" 48
Step 3 – the combination of Steps 1 and 2; the standard error of difference between means (s.e.d.m.) 49
Recap of the calculation of s.e.d.m. from the variance calculated from the individual values 51
The importance of the standard error of differences between means 52
Summary of this chapter 52
Executive summary 2 – Standard error of a difference between two means 56
Spare-time activities 57

8 The *t*-test 58
Introduction 58
The principle of the *t*-test 58
The *t*-test in statistical terms 59
Why *t*? 60
Tables of the *t*-distribution 61
The standard *t*-test 64
The procedure 64
The actual *t*-test 69
t-test for means associated with unequal variances 69
The s.e.d.m. when variances are unequal 70
A worked example of the *t*-test for means associated with unequal variances 73
The paired *t*-test 75
Pair when possible 78
Executive summary 3 – The *t*-test 80
Spare-time activities 82

9 One tail or two? 83
Introduction 83
Why is the analysis of variance *F*-test one-tailed? 83
The two-tailed *F*-test 84
How many tails has the *t*-test? 86
The final conclusion on number of tails 87

10 Analysis of variance – What is it? How does it work? 88
Introduction 88
Sums of squares in the analysis of variance 89
Some "made-up" variation to analyze by Anova 89
The sum of squares table 91

Using Anova to sort out the variation in Table C 91
Phase 1 91
Phase 2 92
SqADS – an important acronym 93
Back to the sum of squares table 96
How well does the analysis reflect the input? 96
End Phase 97
Degrees of freedom in Anova 97
The completion of the End Phase 99
The variance ratio 100
The relationship between "t" and "F" 101
Constraints on the analysis of variance 103
Adequate size of experiment 103
Equality of variance between treatments 103
Testing the homogeneity of variance 104
The element of chance: randomization 104
Comparison between treatment means in the analysis of variance 107
The least significant difference 108
A caveat about using the LSD 110
Executive summary 4 – The principle of the analysis of variance 111

11 Experimental designs for analysis of variance 115
Introduction 115
Fully randomized 116
Data for analysis of a fully randomized experiment 117
Prelims 117
Phase 1 118
Phase 2 118
End Phase 120
Randomized blocks 121
Data for analysis of a randomized block experiment 123
Prelims 123
Phase 1 125
Phase 2 126
End Phase 127
Incomplete blocks 127
Latin square 130
Data for the analysis of a Latin square 131
Prelims 132
Phase 1 134
Phase 2 134

End Phase 135
Further comments on the Latin square design 136
Split plot 137
Executive summary 5 – Analysis of a randomized block experiment 139
Spare-time activities 141

12 Introduction to factorial experiments 143
What is a factorial experiment? 143
Interaction 145
If there is no interaction 145
What if there is interaction? 147
How about a biological example? 148
Measuring any interaction between factors is often the main/only purpose of an experiment 148
How does a factorial experiment change the form of the analysis of variance? 150
Degrees of freedom for interactions 150
The similarity between the "residual" in Phase 2 and the "interaction" in Phase 3 151
Sums of squares for interactions 152

13 2-Factor factorial experiments 154
Introduction 154
An example of a 2-factor experiment 154
Analysis of the 2-factor experiment 155
Prelims 155
Phase 1 156
Phase 2 156
End Phase (of Phase 2) 157
Phase 3 158
End Phase (of Phase 3) 162
Two important things to remember about factorials before tackling the next chapter 163
Analysis of factorial experiments with unequal replication 163
Executive summary 6 – Analysis of a 2-factor randomized block experiment 166
Spare-time activity 169

14 Factorial experiments with more than two factors 170
Introduction 170
Different "orders" of interaction 171

Example of a 4-factor experiment 172
Prelims 173
Phase 1 175
Phase 2 175
Phase 3 176
To the End Phase 183
Addendum – Additional working of sums of squares calculations 186
Spare-time activity 192

15 Factorial experiments with split plots 194
Introduction 194
Deriving the split plot design from the randomized block design 195
Degrees of freedom in a split plot analysis 198
Main plots 198
Sub-plots 198
Numerical example of a split plot experiment and its analysis 201
Calculating the sums of squares 202
End Phase 205
Comparison of split plot and randomized block experiment 206
Uses of split plot designs 209
Spare-time activity 211

16 The *t*-test in the analysis of variance 213
Introduction 213
Brief recap of relevant earlier sections of this book 214
Least significant difference test 215
Multiple range tests 216
Operating the multiple range test 217
Testing differences between means 222
Suggested "rules" for testing differences between means 222
Presentation of the results of tests of differences between means 223
The results of the experiments analyzed by analysis of variance in Chapters 11–15 225
Spare-time activities 236

17 Linear regression and correlation 238
Introduction 238
Cause and effect 239
Other traps waiting for you to fall into 239
Extrapolating beyond the range of your data 239
Is a straight line appropriate? 239
The distribution of variability 244

Regression 244
Independent and dependent variables 245
The regression coefficient (b) 247
Calculating the regression coefficient (b) 248
The regression equation 253
A worked example on some real data 255
The data (Box 17.2) 255
Calculating the regression coefficient (b) – i.e. the slope of the regression line 256
Calculating the intercept (a) 257
Drawing the regression line 257
Testing the significance of the slope (b) of the regression 258
How well do the points fit the line? – the coefficient of determination (r^2) 262
Correlation 263
Derivation of the correlation coefficient (r) 263
An example of correlation 264
Is there a correlation line? 266
Extensions of regression analysis 266
Nonlinear regression 269
Multiple linear regression 270
Multiple nonlinear regression 272
Analysis of covariance 272
Executive summary 7 – Linear regression 274
Spare-time activities 276

18 Chi-square tests 277
Introduction 277
When and where not to use χ^2 278
The problem of low frequencies 279
Yates' correction for continuity 279
The χ^2 test for "goodness of fit" 280
The case of more than two classes 282
χ^2 with heterogeneity 284
Heterogeneity χ^2 analysis with "covariance" 286
Association (or contingency) χ^2 289
2×2 contingency table 289
Fisher's exact test for a 2×2 table 291
Larger contingency tables 292
Interpretation of contingency tables 293
Spare-time activities 294

19 Nonparametric methods (what are they?) **296**
Disclaimer 296
Introduction 296
Advantages and disadvantages of the two approaches 298
Where nonparametric methods score 298
Where parametric methods score 299
Some ways data are organized for nonparametric tests 300
The sign test 300
The Kruskal–Wallis analysis of ranks 301
Kendall's rank correlation coefficient 302
The main nonparametric methods that are available 303

Appendix 1 How many replicates **306**

Appendix 2 Statistical tables **314**

Appendix 3 Solutions to "Spare-time activities" **321**

Appendix 4 Bibliography **337**

Index **339**