Contents

Contributors xviii
From the preface to the first edition xix
From the preface to the second edition xx
From the preface to the third edition xxi
Preface to the fourth edition xxii
About the companion website xxiv

1 The development of veterinary medicine 1
   Michael Thrusfield
   Historical perspective 1
   Domestication of animals and early methods of healing 1
   Changing concepts of the cause of disease 2
   Impetus for change 5
   Quantification in medicine 10
   Contemporary veterinary medicine 12
   Current perspectives 12
   The fifth period 19
   Recent trends 20
   Further reading 25

2 The scope of epidemiology 28
   Michael Thrusfield
   Definition of epidemiology 28
   The uses of epidemiology 29
   Types of epidemiological investigation 32
   Epidemiological subdisciplines 33
   Components of epidemiology 35
   Qualitative investigations 35
   Quantitative investigations 36
   Epidemiology's locale 39
   The interplay between epidemiology and other sciences 39
   The relationship between epidemiology and other diagnostic disciplines 40
   Epidemiology within the veterinary profession 40
   Further reading 41

3 Causality 42
   Michael Thrusfield
   Philosophical background 42
   Causal inference 43
   Methods of acceptance of hypotheses 44
## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Describing disease occurrence</td>
<td>58</td>
</tr>
<tr>
<td>Michael Thrusfield</td>
<td></td>
</tr>
<tr>
<td>Some basic terms</td>
<td>58</td>
</tr>
<tr>
<td>Basic concepts of disease quantification</td>
<td>61</td>
</tr>
<tr>
<td>The structure of animal populations</td>
<td>62</td>
</tr>
<tr>
<td>Contiguous populations</td>
<td>62</td>
</tr>
<tr>
<td>Separated populations</td>
<td>65</td>
</tr>
<tr>
<td>Measures of disease occurrence</td>
<td>67</td>
</tr>
<tr>
<td>Prevalence</td>
<td>67</td>
</tr>
<tr>
<td>Incidence</td>
<td>67</td>
</tr>
<tr>
<td>The relationship between prevalence and incidence rate</td>
<td>70</td>
</tr>
<tr>
<td>Application of prevalence and incidence values</td>
<td>72</td>
</tr>
<tr>
<td>Mortality</td>
<td>72</td>
</tr>
<tr>
<td>Survival</td>
<td>73</td>
</tr>
<tr>
<td>Example of calculation of prevalence, incidence, mortality, case fatality and survival</td>
<td>75</td>
</tr>
<tr>
<td>Ratios, proportions and rates</td>
<td>76</td>
</tr>
<tr>
<td>Mapping</td>
<td>80</td>
</tr>
<tr>
<td>Geographic base maps</td>
<td>80</td>
</tr>
<tr>
<td>Further reading</td>
<td>84</td>
</tr>
</tbody>
</table>

| 5 Determinants of disease | 86 |
| Michael Thrusfield | |
| Classification of determinants | 86 |
| Host determinants | 89 |
| Genotype | 89 |
| Age | 90 |
| Sex | 91 |
| Species and breed | 92 |
| Behaviour | 93 |
| Other host determinants | 93 |
| Agent determinants | 94 |
| Virulence and pathogenicity | 94 |
| Gradient of infection | 97 |
| Outcome of infection | 98 |
| Microbial colonization of hosts | 100 |
| Environmental determinants | 101 |
| Location | 101 |
| Climate | 101 |
| Husbandry | 104 |
### Contents

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>The transmission and maintenance of infection</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td>Michael Thrusfield</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Horizontal transmission</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td>Types of host and vector</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td>Factors associated with the spread of infection</td>
<td>118</td>
</tr>
<tr>
<td></td>
<td>Routes of infection</td>
<td>121</td>
</tr>
<tr>
<td></td>
<td>Methods of transmission</td>
<td>123</td>
</tr>
<tr>
<td></td>
<td>Long-distance transmission of infection</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td>Vertical transmission</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>Types and methods of vertical transmission</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>Immunological status and vertical transmission</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>Transovarial and trans-stadial transmission in arthropods</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>Maintenance of infection</td>
<td>131</td>
</tr>
<tr>
<td></td>
<td>Hazards to infectious agents</td>
<td>131</td>
</tr>
<tr>
<td></td>
<td>Maintenance strategies</td>
<td>132</td>
</tr>
<tr>
<td></td>
<td>Transboundary diseases</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>Further reading</td>
<td>136</td>
</tr>
<tr>
<td>7</td>
<td>The ecology of disease</td>
<td>138</td>
</tr>
<tr>
<td></td>
<td>Michael Thrusfield</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Basic ecological concepts</td>
<td>139</td>
</tr>
<tr>
<td></td>
<td>The distribution of populations</td>
<td>139</td>
</tr>
<tr>
<td></td>
<td>Regulation of population size</td>
<td>142</td>
</tr>
<tr>
<td></td>
<td>The niche</td>
<td>148</td>
</tr>
<tr>
<td></td>
<td>Some examples of niches relating to disease</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>The relationships between different types of animals and plants</td>
<td>152</td>
</tr>
<tr>
<td></td>
<td>Ecosystems</td>
<td>155</td>
</tr>
<tr>
<td></td>
<td>Types of ecosystem</td>
<td>156</td>
</tr>
<tr>
<td></td>
<td>Landscape epidemiology</td>
<td>158</td>
</tr>
<tr>
<td></td>
<td>Nidality</td>
<td>159</td>
</tr>
<tr>
<td></td>
<td>Objectives of landscape epidemiology</td>
<td>161</td>
</tr>
<tr>
<td></td>
<td>Landscape characteristics determining disease distribution</td>
<td>164</td>
</tr>
<tr>
<td></td>
<td>Further reading</td>
<td>165</td>
</tr>
<tr>
<td>8</td>
<td>Patterns of disease</td>
<td>168</td>
</tr>
<tr>
<td></td>
<td>Michael Thrusfield</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Epidemic curves</td>
<td>168</td>
</tr>
<tr>
<td></td>
<td>Kendall’s Threshold Theorem</td>
<td>168</td>
</tr>
<tr>
<td></td>
<td>Basic reproductive number ($R_0$)</td>
<td>169</td>
</tr>
<tr>
<td></td>
<td>Dissemination rate</td>
<td>172</td>
</tr>
<tr>
<td></td>
<td>Common-source and propagating epidemics</td>
<td>172</td>
</tr>
<tr>
<td></td>
<td>The Reed–Frost model</td>
<td>173</td>
</tr>
<tr>
<td></td>
<td>Kendall’s waves</td>
<td>175</td>
</tr>
<tr>
<td></td>
<td>Trends in the temporal distribution of disease</td>
<td>177</td>
</tr>
<tr>
<td></td>
<td>Short-term trends</td>
<td>177</td>
</tr>
</tbody>
</table>
### Contents

- **Cyclical trends** 178
- **Long-term (secular) trends** 179
- **True and false changes in morbidity and mortality** 180
- **Detecting temporal trends: time series analysis** 180
- **Trends in the spatial and temporal distribution of disease** 186
- **Spatial trends in disease occurrence** 186
- **Space–time clustering** 186
- **Further reading** 187

### 9 Comparative epidemiology 189

*Michael Thrusfield*

- Types of biological model 189
- Cancer 191
- Monitoring environmental carcinogens 191
- Identifying causes 192
- Comparing ages 193
- Some other diseases 196
- Diseases with a major genetic component 196
- Some non-infectious diseases 197
- Diseases associated with environmental pollution 198
- Reasoning in comparative studies 199
- Further reading 199

### 10 The nature of data 201

*Michael Thrusfield*

- Classification of data 201
- Scales (levels) of measurement 201
- Composite measurement scales 204
- Data elements 205
- Nomenclature and classification of disease 205
- Diagnostic criteria 207
- Sensitivity and specificity 208
- Accuracy, refinement, precision, reliability and validity 209
- Bias 210
- Representation of data: coding 210
- Code structure 211
- Numeric codes 212
- Alpha codes 213
- Alphanumeric codes 214
- Symbols 215
- Choosing a code 215
- Error detection 216
- Further reading 217

### 11 Data collection and management 219

*Michael Thrusfield*

- Data collection 219
- Questionnaires 219
- Quality control of data 228
- Data storage 229
- Database models 229
- Non-computerized recording techniques 231
Computerized recording techniques 232
Veterinary recording schemes 232
Scales of recording 232
Veterinary information systems 234
Some examples of veterinary databases and information systems 237
Geographical information systems 244
Further reading 248

12 Presenting numerical data 251
Michael Thrusfield and Robert Christley

Some basic definitions 251
Some descriptive statistics 252
Measures of position 253
Measures of spread 254
Statistical distributions 254
The Normal distribution 254
The binomial distribution 255
The Poisson distribution 255
Other distributions 256
Transformations 256
Normal approximations to the binomial and Poisson distributions 257
Estimation of confidence intervals 257
The mean 257
The median 258
A proportion 258
The Poisson distribution 259
Some epidemiological parameters 260
Other parameters 261
Bootstrap estimates 261
Displaying numerical data 262
Displaying qualitative data 262
Displaying quantitative data 263
Monitoring performance: control charts 266
Further reading 269

13 Surveys 270
Michael Thrusfield and Helen Brown

Sampling: some basic concepts 270
Types of sampling 272
Non-probability sampling methods 272
Probability sampling methods 272
What sample size should be selected? 275
Estimation of disease prevalence 275
Detecting the presence of disease 284
The cost of surveys 290
Calculation of confidence intervals 290
Further reading 294

14 Demonstrating association 296
Michael Thrusfield

Some basic principles 296
The principle of a significance test 296
The null hypothesis 297
Errors of inference 297
Multiple significance testing 298
One- and two-tailed tests 298
Independent and related samples 299
Parametric and non-parametric techniques 299
Hypothesis testing versus estimation 300
Sample-size determination 300
Statistical versus clinical (biological) significance 300
Interval and ratio data: comparing means 302
Hypothesis testing 302
Calculation of confidence intervals 303
What sample size should be selected? 304
Ordinal data: comparing medians 304
Hypothesis testing 304
Calculation of confidence intervals 308
What sample size should be selected? 309
Nominal data: comparing proportions 309
Hypothesis testing 310
Calculation of confidence intervals 313
What sample size should be selected? 314
χ² test for trend 314
Correlation 316
Multivariate analysis 317
Statistical packages 318
Further reading 318

15 Observational studies 319
Michael Thrusfield

Types of observational study 319
Cohort, case-control and cross-sectional studies 319
Measures of association 321
Relative risk 321
Odds ratio 323
Attributable risk 325
Attributable proportion 327
Interaction 328
The additive model 328
Bias 330
Controlling bias 332
What sample size should be selected? 335
Calculating the power of a study 336
Calculating upper confidence limits 337
Further reading 338

16 Design considerations for observational studies 339
Robert Christley and Nigel French

Descriptive observational studies 339
Analytical observational studies 340
Design of cohort studies 340
Design of case-control studies 346
Design of cross-sectional analytical studies 352
Overview of other study designs 354
Further reading 359
20 Diagnostic testing 421
Michael Thrusfield

Serological epidemiology 421
Assaying antibodies 421
Methods of expressing amounts of antibody 421
Quantal assay 423
Serological estimations and comparisons in populations 424
Antibody prevalence 424
Rate of seroconversion 425
Comparison of antibody levels 426
Interpreting serological tests 427
Refinement 427
Accuracy 429
Evaluation and interpretation of diagnostic tests 430
Sensitivity and specificity 430
Youden’s index 433
Diagnostic odds ratio 434
Predictive value 434
Likelihood ratios 436
ROC curves 441
Aggregate-level testing 443
Multiple testing 444
Diagnostic tests in import risk assessment 446
Guidelines for validating diagnostic tests 447
Validating diagnostic tests when there is no gold standard 448
Agreement between tests 450
Practical application of diagnostic tests 456
Further reading 456

21 Surveillance 457
Michael Thrusfield

Some basic definitions and principles 457
Definition of surveillance 457
Goals of surveillance 458
Types of surveillance 459
Some general considerations 461
Sources of data 464
Mechanisms of surveillance 471
Surveillance networks 475
Surveillance in less-economically-developed countries: participatory epidemiology 475
Principles of participatory epidemiology 477
Techniques of data collection 478
Strengths and weaknesses of participatory epidemiology 481
Some examples of participatory epidemiology 483
Companion-animal surveillance 483
Wildlife surveillance 485
Aquatic-animal surveillance 485
Assessing the performance of surveillance systems 486
Improving the performance of surveillance: risk-based surveillance 486
Further reading 488

22 Statistical modelling 492
Robert Christley and Peter J. Diggle

Simple linear regression models 492
Key assumptions of linear regression models 495
Modelling more than one input variable 499
Handling categorical input variables 500
Non-linear modelling of quantitative input variables 502
Additive models 502
Categorization of the input variable 502
Transformation of the input and/or output variable 504
Piece-wise regression 504
Modelling interactions 505
Model selection 506
Modelling binary outcomes 509
Generalized linear models 511
The multiple logistic regression model 511
Model selection for logistic regression models 512
Diagnostic checking of logistic regression models 513
Generalized additive models 514
Modelling clustered data 514
Further reading 519

23 Mathematical modelling 520
Michael Thrusfield

Types of model 521
Modelling approaches 521
Deterministic differential calculus modelling 521
Stochastic differential calculus modelling 525
Empirical simulation modelling 526
Process simulation modelling 527
Monte Carlo simulation modelling 528
Matrix population modelling 530
Network population modelling 532
Contact-network modelling 533
Systems modelling 534
The rational basis of modelling for active disease control 534
Available knowledge, and the functions of models 534
From theory to fact 535
Model building 536
Further reading 538

24 Risk analysis 540
Michael Thrusfield and Louise Kelly

Definition of risk 540
Risk analysis and the 'precautionary principle’ 543
Risk analysis in veterinary medicine 543
Components of risk analysis  545
  Hazard identification  546
  Risk assessment  546
  Risk management  548
  Risk communication  551
  Qualitative or quantitative assessment?  551
  Semi-quantitative risk assessment  551
  Qualitative risk analysis  552
  Framework for qualitative risk assessment  552
  Qualitative risk assessment during epidemics  554
  Quantitative risk analysis  556
  Framework for quantitative risk assessment  556
  What level of risk is acceptable?  560
  Further reading  563

25  Economics and veterinary epidemiology  565
Keith Howe and Michael Thrusfield
  General economic concepts  565
  Production functions  565
  Disease and animal production functions  566
  Value and money  567
  Money and prices  567
  Opportunity cost  568
  Technical and economic efficiency  568
  Positive and normative economics  569
  Levels of aggregation  569
  Disease contained at farm level  569
  Disease not contained at farm level  570
  Zoonotic disease  570
  Disease at international level  571
  Evaluating disease-control policies  575
  Components of disease costs  576
  Optimum control strategies  577
  Partial budgets  579
  Social cost–benefit analysis (CBA)  579
  Summary of methods  582
  Further study  582
  Further reading  584

26  Health schemes  586
Michael Thrusfield
  Private health and productivity schemes  586
  Structure of private health and productivity schemes  586
  Dairy health and productivity schemes  588
  Pig health and productivity schemes  591
  Sheep health and productivity schemes  592
  Beef health and productivity schemes  594
  National schemes  597
  Accredited/attested herds  597
  Health schemes  598
  Companion-animal schemes  599
  Further reading  603
27 The control and eradication of disease 604

Michael Thrusfield

Definition of ‘control’ and ‘eradication’ 604
Strategies of control and eradication 605
Important factors in control and eradication programmes 616
Outbreak investigation 623
Cause known: foot-and-mouth disease 623
Cause unknown: chronic copper poisoning 625
The epidemiological approach to investigation of outbreaks 626
Veterinary medicine in the 21st century 628
Livestock medicine 628
Companion-animal medicine 629
Further reading 630

General reading 633

Appendices 635
Appendix I: Glossary of terms 636
Appendix II: Basic mathematical notation and terms 641
Appendix III: Some computer software 643
Appendix IV: Veterinary epidemiology on the Internet 648
Appendix V: Student’s t-distribution 650
Appendix VI: Multipliers used in the construction of confidence intervals based on the Normal distribution, for selected levels of confidence 651
Appendix VII: Values of exact 95% confidence limits for proportions 652
Appendix VIII: Values from the Poisson distribution for calculating 90%, 95% and 99% confidence intervals for observed numbers from 0 to 100 658
Appendix IX: The χ² distribution 660
Appendix X: Technique for selecting a simple random sample 661
Appendix XI: Sample sizes 663
Appendix XII: The probability of detecting a small number of cases in a population 669
Appendix XIII: The probability of failure to detect cases in a population 671
Appendix XIV: Sample sizes required for detecting disease with probability, p, and threshold number of positives 672
Appendix XV: Probabilities associated with the upper tail of the Normal distribution 676
Appendix XVI: Lower- and upper-tail probabilities for W, the Wilcoxon–Mann–Whitney rank-sum statistic 678
Appendix XVII: Critical values of T⁺ for the Wilcoxon signed ranks test 683
Appendix XVIII: Values of K for calculating 95% confidence intervals for the difference between population medians for two independent samples 685
Appendix XIX: Values of K⁺ for calculating 95% confidence intervals for the difference between population medians for two related samples 688
Appendix XX: Common logarithms (log₁₀) of factorials of the integers 1–999 689
Appendix XXI: The correlation coefficient 691
Appendix XXII: The variance-ratio (F) distribution 692

References 694

Index 841