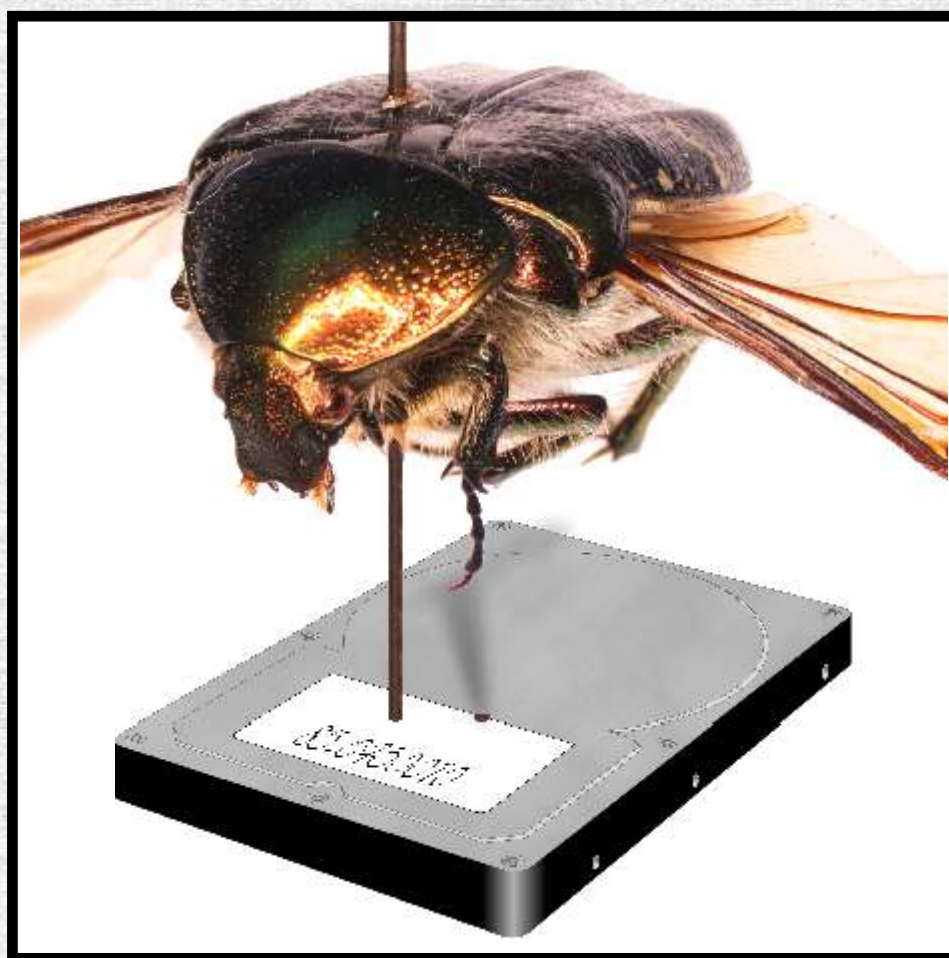


**The Development and Implementation of Software for
Palaeoenvironmental and Palaeoclimatological Research:
The Bugs Coleopteran Ecology Package (BugsCEP)**

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Archaeology and Environment 23

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(BugsCEP)**

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Title

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Abstract

This thesis documents the development and application of a unique database orientated software package, BugsCEP, for environmental and climatic reconstruction from fossil beetle (Coleoptera) assemblages. The software tools are described, and the incorporated statistical methods discussed and evaluated with respect to both published modern and fossil data, as well as the author's own investigations.

BugsCEP consists of a reference database of ecology and distribution data for over 5 800 taxa, and includes temperature tolerance data for 436 species. It also contains abundance and summary data for almost 700 sites - the majority of the known Quaternary fossil coleopteran record of Europe. Sample based dating evidence is stored for a large number of these sites, and the data are supported by a bibliography of over 3 300 sources. Through the use of built in statistical methods, employing a specially developed habitat classification system (Bugs EcoCodes), semi-quantitative environmental reconstructions can be undertaken, and output graphically, to aid in the interpretation of sites. A number of built in searching and reporting functions also increase the efficiency with which analyses can be undertaken, including the facility to list the fossil record of species found by searching the ecology and distribution data. The existing Mutual Climatic Range (MCR) climate reconstruction method is implemented and improved upon in BugsCEP, as BugsMCR, which includes predictive modelling and the output of graphs and climate space maps.

The evaluation of the software demonstrates good performance when compared to existing interpretations. The standardization method employed in habitat reconstructions, designed to enable the inter-comparison of samples and sites without the interference of differing numbers of species and individuals, also appears to be robust and effective. Quantitative climate reconstructions can be easily undertaken from within the software, as well as an amount of predictive modelling. The use of jackknifing variants as an aid to the interpretation of climate reconstructions is discussed, and suggested as a potential indicator of reliability. The combination of the BugStats statistical system with an enhanced MCR facility could be extremely useful in increasing our understanding of not only past environmental and climate change, but also the biogeography and ecology of insect populations in general.

BugsCEP is the only available software package integrating modern and fossil coleopteran data, and the included reconstruction and analysis tools provide a powerful resource for research and teaching in palaeo-environmental science. The use of modern reference data also makes the package potentially useful in the study of present day insect faunas, and the effects of climate and environmental change on their distributions. The reconstruction methods could thus be inverted, and used as predictive tools in the study of biodiversity and the implications of sustainable development policies on present day habitats.

Keywords: environmental archaeology, Quaternary science, Coleoptera, beetles, database, environmental reconstructions, climate reconstructions, software, Mutual Climatic Range, MCR, palaeoentomology

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2007



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Contents

List of figures	v
List of tables	ix
List of abbreviations	x
Database terminology	xi
General terminology	xi
The structure of the thesis	xii
Acknowledgements	xii
1 Introduction	1
1.1 Aims of the Thesis	1
1.2 Scientific Background	2
1.2.1 Databases in Quaternary science	2
1.2.1.1 General Quaternary data structure	3
1.2.2 The BugsCEP structure in brief	3
1.2.3 What is BugsCEP and what does it replace?	4
1.2.4 Related databases	4
1.2.5 Taxonomy and fossils	6
1.2.6 The archaeological and contemporary contexts	7
2 The Development of BugsCEP	9
2.1 Introduction	9
2.2 Database and Software Background	9
2.2.1 Relational database design	9
2.2.2 The BugsCEP database structure	11
2.2.3 Overview of BugsCEP software features	13
2.3 Developmental Strategy	14
2.3.1 Primary developmental aims	15
2.3.2 Secondary aims	15
2.3.3 Development platform	16
2.4 Database Structural Changes	16
2.4.1 Bugs database structure and contents	16
2.4.2 Conversion of Bugs2000 data	18
2.4.3 Database structural compromises	18
2.4.4 Problems and potential problems with the BugsCEP structure	20
2.5 Program Development	22
2.5.1 Summary of deficiencies in the previous version (Bugs2000)	22
2.5.2 Main improvements in the BugsCEP system	22
2.6 Testing	24
2.6.1 Developer testing	24
2.6.2 User-based testing	25
2.7 Presentations and Publications	25
2.7.1 Publications about or with direct use of Bugs	25
2.7.2 Unpublished presentations	26
2.7.3 Poster presentations	26
2.7.4 A note on other publications using Bugs (2000/CEP)	26
2.8 A Brief Developmental History of Bugs	27
2.8.1 Design criteria for Bugs	27
2.8.2 Implementing the design criteria	27
2.8.3 Version history	28
2.8.4 Bugs spin-offs	30
2.8.4.1 Slugs – Molluscan Database	30
2.8.4.2 EgBugs – The Egyptian Coleoptera Database	30
2.8.4.3 Other embryonic versions	31
2.8.5 Other Related Software	32
2.8.5.1 MS-DOS MCR Software – RECON & RECON2 and related programs	32
2.8.5.2 BugsMCR (standalone version)	32
2.8.5.3 BugStats (standalone version)	32
3 BugsCEP Database System Description	33
3.1 Data Area Descriptions	33

3.1.1	Common data area.....	34
3.1.1.1	Master species list and taxonomic code	34
3.1.1.2	Synonyms	34
3.1.1.3	Taxonomic notes	35
3.1.1.4	Measurable attributes	35
3.1.1.5	Identification keys (provided by Peter Skidmore).....	35
3.1.1.6	Bibliography.....	35
3.1.2	Modern reference/calibration data.....	36
3.1.2.1	Biology and distribution text abstracts	36
3.1.2.2	Ecology summary codes (Bugs EcoCodes & Koch ecology codes).....	37
3.1.2.3	Red Data Book (RDB) classifications.....	37
3.1.2.4	Species associations	38
3.1.2.5	Seasons of adult activity.....	38
3.1.2.6	Climate calibration data (thermal envelopes and summaries).....	38
3.1.3	Fossil/site data area	39
3.1.3.1	Sites.....	39
3.1.3.2	Site descriptive data and metadata	40
3.1.3.3	Countsheets: species lists, samples & abundance data.....	40
3.1.3.4	Sample dates.....	41
3.2	Record Enumeration & Database Size.....	42
3.2.1	Sites overview	44
3.2.2	Countsheets: species lists, samples & abundance data.....	45
3.2.3	Sample dates.....	46
3.2.3.1	Radiometric dates.....	47
3.2.3.2	Calendar dates	48
3.2.3.3	Period dates	49
3.3	User Base	50
3.4	The BugsCEP Program - Detailed Description.....	51
3.4.1	BugsCEP Main Screen – basic data retrieval	52
3.4.1.1	Section (1): Title bar, menu bar and component buttons.....	54
3.4.1.2	Section (2): Navigation panel.....	54
3.4.1.3	Section (3): Information tabs, and section (4) Information area.....	56
3.4.1.4	Section (5): Additional buttons and administrative controls	59
3.4.2	Site and Countsheet Management – adding/retrieving sites and abundance data.....	62
3.4.2.1	The Site Manager	62
3.4.2.2	Site Information screen	63
3.4.2.3	Managing countsheets and entering abundance data.....	64
3.4.2.4	Importing MS Excel spreadsheets	67
3.4.2.5	The Date Explorer	70
3.4.3	Environmental reconstruction - BugStats.....	71
3.4.3.1	Calculations options	73
3.4.3.2	Chart options	74
3.4.3.3	Creating EcoCode outputs.....	74
3.4.3.4	Seeing the Bugs EcoCode definitions	76
3.4.3.5	Calculating coefficients of similarity	76
3.4.4	Climate reconstruction - BugsMCR	78
3.4.5	The Search Interface.....	83
3.4.5.1	A worked example.....	85
3.4.6	The help files.....	87
3.5	Reporting & Exporting Functions.....	88
3.5.1	Single species data	88
3.5.2	Bibliographic data	89
3.5.3	Site reports.....	89
3.5.4	Reporting search results	90
3.6	The Addition of Taxa, Biology/Distribution Data and References.....	93
4	BugStats: Software for Environmental Reconstruction and Statistics from Beetle Assemblages.....	95
4.1	Why BugStats?.....	95
4.2	Background	96
4.2.1	Quantitative methods in Quaternary science	96

4.2.1.1	Statistics in (palaeo)entomology and environmental science.....	96
4.2.1.2	Taphonomy and the representation of taxa in samples	97
4.2.2	Biogeography, evolution and palaeoecology	97
4.2.3	Classification.....	98
4.2.3.1	Habitat classification and palaeoecology	100
4.2.3.2	Further notes on habitat classification methods	101
4.3	The Bugs EcoCode Classification System, and the BugStats Environmental Reconstruction Software.....	101
4.3.1	Bugs EcoCode classification system description	101
4.3.2	Bugs EcoCode designations and their implications	104
4.3.3	EcoFig calculations, transformation and standardization.....	105
4.3.3.1	Excluding taxa not identified to species level	106
4.3.3.2	Logarithmic transformation	106
4.3.3.3	Standardization.....	109
4.3.3.4	EcoFig diagram creation	110
4.3.3.5	Sample by sample EcoCode report	111
4.3.3.6	Alternative standardization possibilities	111
4.3.3.7	Final note on the use of BugStats options	112
4.3.4	Known issues with EcoCodes	112
4.3.4.1	Geographical variation in habitat preference	112
4.3.4.2	Indicators and standardization.....	113
4.3.4.3	Indicators and diversity	113
4.3.5	Correlation coefficients.....	113
4.4	The mechanics of BugStats.....	114
4.4.1	EcoFig calculations and diagram creation.....	114
4.4.2	EcoCode reports.....	115
4.4.3	Coefficient calculation	115
4.5	Further developments and additional methods	115
4.6	Conclusions.....	117
5	BugsMCR: Software for MCR Temperature Reconstruction from Beetle Assemblages....	119
5.1	Background and Software Development	119
5.1.1	The mutual climatic range (MCR) method in brief.....	119
5.1.2	The BugsMCR implementation	121
5.1.2.1	Species thermal envelopes	122
5.1.2.2	Calculations and overlaps	124
5.1.2.3	Graphs	126
5.1.2.4	Advanced MCR.....	126
5.1.3	Predicting potential changes in geographical range	127
5.2	MCR – Problems and Possibilities	130
5.2.1	Requirements for quantitative reconstructions.....	130
5.2.2	MCR and urban deposits.....	132
5.2.3	Problems with MCR correction/calibration	132
5.2.4	Ubiquity analysis.....	134
5.2.5	Calculation of relative warm/cold components.....	134
5.2.6	The use of jackknifing to investigate or enhance the reliability of results	135
5.2.6.1	Multiple removal jackknifing as a reliability index	139
5.2.6.2	Potential problems with jackknifing and MCR.....	139
5.3	Conclusions and Future Directions.....	140
6	Case Studies – testing BugsCEP with real data	141
6.1	Modern Case Study: Forest-Farmland Pitfall Trap Transects in Lammi, Finland.....	142
6.1.1	Aims.....	142
6.1.2	Introduction.....	142
6.1.3	Methods.....	143
6.1.4	Results and preliminary discussion.....	144
6.1.5	Further discussion	148
6.1.6	Conclusions and implications for BugStats.....	149
6.2	Fossil Case Study: 140 000 year Peat Sequence, La Grande Pile, France.....	150
6.2.1	Aims.....	150
6.2.2	Methods.....	150

6.2.3	Results and general comparison	151
6.2.4	Discussion and detailed comparison of specific habitat groups	155
6.2.5	How are Ponel's faunal and chronological groups affected by the use of standardized results and sample correlations?	160
6.2.6	Conclusions	164
6.3	Fossil Case Study: Early Holocene Environmental and Climate Change at Hemavan, Northern Sweden.....	164
6.3.1	Aims	164
6.3.2	Site, samples and methods.....	165
6.3.3	Results	168
6.3.4	Discussion	172
6.3.5	Evidence for early Holocene climate change	173
6.3.6	Conclusions	174
6.4	Fossil Case Study: Two 'Wells' at the Archaeological Site Lockarp 7B, Sweden.....	174
6.4.1	Aims and introduction.....	174
6.4.2	Methods.....	175
6.4.3	Results and discussion.....	176
6.4.3.1	Feature 14495	179
6.4.3.2	Feature 26551	180
6.4.4	Conclusions	181
6.5	Preliminary Fossil Results from Lake Njulla, Abisko, Sweden.....	182
6.5.1	Introduction	182
6.5.2	Preliminary results.....	183
6.5.3	Conclusions	184
6.6	Modern Case Study: Pitfall Trap Data from the area of Gården under Sandet (GUS), Greenland.	184
6.6.1	Aims and introduction.....	184
6.6.2	Results	184
6.6.3	Discussion	185
6.6.4	Conclusions	187
6.7	Fossil Case Study: Climate and Environmental Change in Europe over the Past 20 000 ¹⁴ C years Reconstructed from Coleopteran Remains	187
6.7.1	Aims	187
6.7.2	Introduction	188
6.7.3	Sites	188
6.7.4	Methods.....	192
6.7.5	Results and discussion.....	193
6.7.6	An experiment in large scale environmental reconstruction, and a test of the BugStats %SumRep standardization method.....	201
6.7.6.1	Relationships between reconstructed temperatures and habitats	204
6.7.7	Conclusions	205
7	Conclusions.....	207
7.1	Wider Applications	208
7.2	Databasing the Humanities	208
7.3	Future Directions and Final Thoughts.....	209
8	References.....	211

List of figures

Figure 1.1. Typical Quaternary science sample hierarchy from project to sample level. <i>Italics</i> show where the BugsCEP name differs from the common usage. A sample contains abundance data for each species found in it (see Table 1.1).	3
Figure 2.1. Relational database terminology, and the normalized taxonomic index structure of the SEAD database (Buckland <i>et al.</i> , 2006).	10
Figure 2.2. BugsCEP program frontend-backend structure, showing user, developer and data manager interaction.	12
Figure 2.3. BugsCEP backend (database) structure. Boxes represent data tables with lists of their fields enclosed. Lines represent relationships between the tables (see Figure 2.1 for explanation). Note that a number of lookup and reference tables have been omitted to improve clarity. The three table groups, or data areas, Common, Modern and Fossil/Site are explained in Chapter 3.	13
Figure 2.4. Bugs2000 database structure. Note that the relationships between the Biblio and SHNEW are symbolic, and represent programmed links rather than enforced relationships.	17
Figure 2.5. BugsCEP database structure, repeated from Figure 2.3 to allow for easier comparison with the structure of the previous version, Bugs2000 (Figure 2.4).	17
Figure 2.6. Start-up screen of Slugs v.2 prototype molluscan database	30
Figure 2.7. Start-up screen of EgBugs – the Egyptian Entomology Database.	31
Figure 3.1. Screenshot: BugsCEP start-up screen.	33
Figure 3.2. Structure of the Red Data Book (RDB) system and code (classification) data area.	38
Figure 3.3. Structure of the site and samples area of the database, illustrating how data items are displayed (top) and saved (bottom). Note that the empty cells in the countsheet are not saved in the <i>TFossil</i> table.	41
Figure 3.4. Bar graph showing number of sites per country. Lighter parts of the bars represent sites with only summary information and no abundance data. ‘Other’ shows the total sum for all countries with less than nine sites per country.	44
Figure 3.5. Geographical location of sites in the BugsCEP database. Mercator projection.	45
Figure 3.6. Map showing location of sites with stratigraphic sequences, archaeological contexts and no countsheets in the BugsCEP core region.	46
Figure 3.7. Histogram showing number of radiometric dates per 5 000 year period (bin) over the last 100 000 radiometric years.	47
Figure 3.8. Histogram showing number of radiometrically dates per 1 000 year period (bin) over the last 20 000 radiometric years.	48
Figure 3.9. Histogram showing number of calendar dates per 250 year period over the last 5 000 years (corrected to calendar BP where present = 1950 for limited comparability with radiometric ages).	48
Figure 3.10. Bar chart showing number of dates stored per time period. The ‘Other’ category is the sum of all periods with less than ten dates.	49
Figure 3.11. Screenshot: BugsCEP main screen showing biology and distribution data for <i>Cicindela sylvatica</i> L.	53
Figure 3.12. Screenshot: Bibliography pop-up showing references for <i>Cicindela sylvatica</i> L.	53
Figure 3.13. BugsCEP Main Screen areas: (1) Title bar, menu bar and component buttons; (2) Navigation panel; (3) Information tabs; (4) Information area; (5) Additional buttons and administrative controls. (The background image is the same as Figure 3.11).	54
Figure 3.14. Screenshot: Taxonomic Explorer (Main Screen Navigation).	55
Figure 3.15. Screenshot: Taxonomic code browser (Main Screen Navigation).	56
Figure 3.16. Screenshot: Main screen, synonyms panel showing data for <i>Nebria rufescens</i> (Ström.).	57
Figure 3.17. Screenshot: Fossil/Site Records panel, showing sites with radiometrically dated samples containing <i>Nebria rufescens</i> (Ström.).	58
Figure 3.18. Screenshot: Ecological Summary panel for <i>Aphodius foetens</i> (F.).	59
Figure 3.19. Screenshot: Synonym Browser, showing search for ‘ <i>gyllenhalii</i> ’. The Find dialog has been positioned to overlap the browser for ease of use.	60
Figure 3.20. Screenshot: First two couplets of the key to <i>Agriotes</i> species.	61
Figure 3.21. Screenshot: Species associations for <i>Dyschirius nitidus</i> (Dej.).	61
Figure 3.22. Screenshot: BugsCEP Site Manager, with the site ‘Brigg’ selected.	63
Figure 3.23. Screenshot: Site Information Screen showing details for Brigg (Buckland, 1981).	64
Figure 3.24. Screenshot: The Countsheet Manager showing the two countsheets stored for Brigg.	64
Figure 3.25. Screenshot: The Countsheet Explorer spreadsheet display, showing part of the abundance data for the countsheet ‘Brigg Column_bugsdata.xls’. Taxa names fill the first column and sample names form the remaining column headers.	65
Figure 3.26. Screenshot: Species List Editor.	66
Figure 3.27. Screenshot: Samples Manager showing the first three samples of the stratigraphic sequence from the countsheet ‘Brigg Column_bugsdata.xls’. Sample depths have been entered for the first two samples.	67

Figure 3.28. Spreadsheet format for import of MS Excel files into BugsCEP. Note that the divider between Genus and species could also be a space.	68
Figure 3.29. Screenshot: BugsCEP Import Wizard showing stages one and two completed in the import of the hemavan_bugsdata.xls MS Excel file.	68
Figure 3.30. Screenshot: BugsCEP File Converter, having attempted to automatically convert the file hemavan_old_format.xls. Blank cells in the first few columns of the New Countsheet (bottom) indicate a failed match – the original name being shown in column ‘F1’. Names marked with an asterisk are uncertain matches. Column widths have been adjusted for clarity, by drag the right hand edge of the column headers.	69
Figure 3.31. Screenshot: Message displayed on completion of the automatic phase of imported file conversion. All problems indicated here must be corrected manually in the File Converter before import can continue.	70
Figure 3.32. Screenshot: Date Explorer showing calendar dates for first sample in the countsheet Sandnes Felt I, Greenland.	71
Figure 3.33. Screenshot: Date Explorer showing a radiocarbon dated sample from Messingham, UK.	71
Figure 3.34. Screenshot: BugStats main screen with the site Stóraborg and countsheet ‘Storaborg_bugsdata.xls’ selected. The ‘Graph title’ has been entered manually.	72
Figure 3.35. Screenshot: the first few charts of a Bugs EcoFig for Stóraborg, as opened in MS Excel for the first time.	75
Figure 3.36. Screenshot: Start of report showing a sample by sample breakdown of the taxa found at Stóraborg, including their abundances and Bugs EcoCode designations.	76
Figure 3.37. Screenshot: The coefficients calculation interface, with Stóraborg selected.	77
Figure 3.38. Screenshot: Coefficients output opened in MS Excel for first time.	78
Figure 3.39. Screenshot: The BugsMCR interface with the Saint Bees site and ‘Saint Bees Coope_bugsdata.XLS’ countsheet activated.	79
Figure 3.40. Thermal reconstruction from the Saint Bees site, using the ‘Closest to 100%’ overlap option. Note that the temperature axes may differ on output, and must be scaled manually. All results are in degrees Celcius, and the warming of both summer and winter temperatures through the sequence can clearly be seen from left to right.	80
Figure 3.41. Climate space maps for two samples from Saint Bees, as exported by BugsMCR, showing (a) a 100 % overlap scenario and (b) a non 100 % overlap scenario with a complex area of maximum overlap. See Chapter 5 for further a more detailed explanation of envelopes and overlaps.	82
Figure 3.42. Screenshot: MCR calculation progress indicator, showing that sample 35 out of 35 is being calculated.	82
Figure 3.43. Bugs Search Explorer, with interface parts as follows: (1) Criteria type tabs (top) and search criteria selection for the active tab; (2) Action buttons; (3) Current species list (search results); (4) Current search session log; (5) Report/export buttons.	83
Figure 3.44. Flow diagram illustrating the sequence of events when using the Bugs Search Explorer.	85
Figure 3.45. Search results report showing ‘Just the names’ of the taxa which are RDB classified as extinct in the UK, classified as aquatic and known from Sweden.	86
Figure 3.46. Final page of the ‘Just the names’ search results report, showing the sequence of events that lead to the final species list (the search log).	87
Figure 3.47. Screenshot: The BugsCEP help contents page, the links below the title bar providing navigation.	87
Figure 3.48. Screenshot: The report toolbar, displayed at the top of all report previews.	88
Figure 3.49. Screenshot: The Report Generator, which allows the user to specify which type of report to create. It is used in several areas of the program, and has a number of variations as shown by a and b	89
Figure 3.50. Site report, full version, showing part of the first and last pages of the 82 page report generated for the Saint Bees site. The first page shows site summary information and the first taxa from the site, and the last page shows the last few references cited in the biology and distribution data.	90
Figure 3.51. Search results report using the ‘Names; EcoCodes; RDB’ option. Each taxon name is followed by its BugsCEP habitat and Red Data Book classifications.	91
Figure 3.52. Search results report using the ‘Names; Synonyms; Taxonomic Notes’ option.	91
Figure 3.53. Search results report using the ‘Names; Biology & Distribution texts with full references’ option.	92
Figure 3.54. Report showing the first few sites from which the seven species shown in Figure 3.45, which were retrieved through the Search Explorer, are known.	93
Figure 4.1. Number of Bugs EcoCodes per taxon.	105
Figure 4.2. Number of taxa per Bugs EcoCode habitat class. Taxa can be present in more than one general class, but only one ‘Indicator’ class.	105
Figure 4.3. <i>Unmodified</i> BugStats EcoFigs for Saint Bees (Coope & Joachim, 1980), note that the basal sample is at the top of each diagram. Settings, from the left: 1A: No abundance, Raw; 2A: Abundance weighted, Raw; 1B: No abundance, %SumRep; 2B: Abundance weighted, %SumRep (see 4.3.3.3).	107

Figure 4.4. Flow diagram illustrating the sequence of events that create an EcoFig diagram from site data.	108
Figure 5.1. An illustration of the derivation of temperature values (TValues) using the MCR method, showing the mutual climatic range (MCR) for three species in climate space.	120
Figure 5.2. Thermal envelope for <i>Carabus problematicus</i> Hbst. as stored in BugsCEP, showing how taxonomic code links the envelope data to ecology data through the master species index. The original envelope, as stored in the beetle.dat data file for the MCRBirm RECON software is shown in the inset to the bottom left.	123
Figure 5.3. Screenshot: Comparison of BugsCEP taxa with names of taxa as stored in the original MCRBirm software. The 'RECON Nr' field shows the numbers used as input strings in the original RECON(struction) component of the MCRBirm software.	124
Figure 5.4. Comparison of exported climate space maps for Saint Bees (Coope & Joachim, 1980) sample s50 as processed by (a) BugsMCR and (b) RECON. Note the difference in reconstructed temperatures caused by the definition of maximum overlap cells. Both maps have been shaded, had scales added and the area of maximum overlap highlighted. The BugsMCR output has been rounded to the nearest percent for clarity, and the RECON values are in percent/10 as output by the program. The scales indicate the upper boundary of climate cells in degrees Celsius.	125
Figure 5.5. Screenshot: Advanced MCR interface, showing the sample selection panel on the left and numerous options on the right.	126
Figure 5.6. Screenshot: The BugsMCR Predictions interface with the thermal envelope limits for <i>Diacheila arctica</i> (Gyll.) selected and copied to the 'Ranges' panel.	128
Figure 5.7. Cross section of a sample climate space map, along the TRange = 21°C line, showing % of species in each TMax 1°C climate cell. Note the square nature of the curve, and the plateau like nature of the 100 % area, indicating the equal probability of any cell in this area.	133
Figure 5.8. Chart showing jackknife limits for all temperature variables for Saint Bees sample s50. The thick bars show the standard MCR results, and the extensions the jackknife extremes. The source data is presented in Table 5.6.	137
Figure 6.1. Map of case study sites discussed in this chapter. See BugsCEP for the location of other sites mentioned.	141
Figure 6.2. Mean adjusted catch (and SE) of carabids of three habitat groups along forest - farmland transects. Black/white shading represents different trapping episodes. Note that the Forest species y-axis has been rescaled in this thesis to match the other habitat scales. [Reproduced with permission from Koivula <i>et al.</i> (2004)].	142
Figure 6.3. BugStats EcoFig output (edited) for Koivula <i>et al.</i> (2004) reconstructed grouped trap data. See text for discussion of variations. Note that the x-axes are different for each raw diagram. NSpec = Number of species.	146
Figure 6.4. All taxa EcoFigs for La Grande Pile. Diagrams (a) and (b) show abundance weighted, and taxa only, standardized values respectively. Diagrams (c) and (d) show abundance weighted, and taxa only, raw values respectively. Number of taxa and abundance totals are shown in Figure 6.6.	153
Figure 6.5. Species identifications only EcoFig for La Grande Pile. Diagrams (a) and (b) show abundance weighted, and taxa only, standardized values respectively. Diagrams (c) and (d) show abundance weighted, and taxa only, raw values respectively. Number of taxa and abundance totals are shown in Figure 6.6.	154
Figure 6.6. La Grande Pile, comparison of number of taxa and individuals, showing all taxa and species level only identifications for comparison. Ponel's (a) samples, (b) faunal units, and (c) the pollen chronozones of Beaulieu & Reille (1992) are shown. Note the different scales on abundance and NSpec graphs.	155
Figure 6.7. Comparison of woodland habitat numbers for Ponel's classes: Conifer dependant, Deciduous dependant, Tree-dependent; and the equivalent raw, species level identification only, representation counts in BugsCEP: <i>Indicators: Coniferous</i> , <i>Indicators: Deciduous</i> , <i>Wood and trees</i> respectively. T = No. of Taxa, I = No. of Individuals. Sample 29 is absent from the original figure and therefore also the BugStats charts.	156
Figure 6.8. Comparison of aquatic habitat numbers for Ponel's classes: Aquatics, Standing-water, Running-water; and the equivalent for all taxa in BugsCEP: <i>Aquatics</i> , <i>Indicators: Standing water</i> , <i>Indicators: Running water</i> respectively.	157
Figure 6.9. Comparison of dung habitat numbers for Ponel's coprophagous class and the equivalents in BugsCEP: <i>Indicators: Dung</i> , <i>Dung/foul habitats</i> and <i>Pasture/Dung</i> . Note the different scales.	158
Figure 6.10. A comparison of the BugsMCR temperature reconstruction for La Grande Pile with that provided by Ponel. Numbers of taxa and individuals used in the BugsMCR calculations are provided on the right, and samples where the area of maximum overlap contains <100 % of taxa are indicated by lighter shading.	160
Figure 6.11. Comparison of Ponel's faunal units with those derived from correlation coefficients for neighbouring samples, and possible implications of BugStats standardized outputs on the original faunal	

units. Coefficient based sample groups (B1-B7.4) are shaded by the average of the coefficient values for samples in the group. 0 = no similarity, 1 = total similarity.	162
Figure 6.12. Panorama photograph of the Hemavan bog taken from the sampling location.	164
Figure 6.13. Map showing the Hemavan site and location of the sample profile.	165
Figure 6.14. Photograph of the sampling location, with remains of Engelmark (1996) section in the foreground on the left. Paul Buckland is documenting the vegetation (and simuliids) in the background.	166
Figure 6.15. Photograph showing the sampling pit at two stages of excavation. The scale is approximate and for illustration only. A dark, more humified band can be seen at c. 100 cm, and the peat-clay transition is visible at about 135 cm.	167
Figure 6.16. Bugs EcoFigs and other biological proxies for Hemavan. Standardized beetle reconstructions with (a) abundance weighting and (b) taxa only. Diagram (c) shows summary pollen percentage data, and (d) raw plant macrofossil counts. Radiocarbon dates are uncalibrated, and transferred by stratigraphic correlation.	171
Figure 6.17. MCR reconstruction of palaeotemperatures from Hemavan. Uncalibrated ^{14}C dates are shown on the diagram; 1σ calibrated ranges U-2692: 5122-6184 BP and U-2695: 8599-9243 BP (Oxcal version 4, Bronk Ramsey, 1995). Present day temperatures: TMax: 8 to 10°C; TMin: -15 to -12°C (SMHI, 2005).	172
Figure 6.18. Stratigraphy and sample locations in feature 14495, Lockarp 7B. Stratigraphy provided by Johan Linderholm; archaeological sediment descriptions can be found in Eliasson & Kishonti, (2003).	175
Figure 6.19. Stratigraphy of feature 26551, Lockarp 7B. Insects were only preserved in the bottom 20 cm of the sequence. Stratigraphy provided by Johan Linderholm; archaeological sediment descriptions can be found in Eliasson & Kishonti, (2003).	176
Figure 6.20. BugStats output for Lockarp 7B feature 14495. Both diagrams are standardized, showing (a) abundance weighted and (b) taxa only results.	179
Figure 6.21. BugStats output for Lockarp 7B feature 26551, illustrating the importance of sample standardization (see text). Diagrams (a) and (a) show standardized abundance weighted and taxa only results respectively; diagrams (c) and (d) show raw counts, abundance weighted and taxa only respectively.	181
Figure 6.22. Correlation of cores from Lake Njulla, Abisko, Sweden. Lines indicate correlation horizons between the cores. Core group 3 was taken with a larger corer bore and was not able to penetrate as deep as the others. Core group 1 is considered as the most reliable set of cores.	183
Figure 6.23. BugStats output for GUS modern data, showing (a) standardized, taxa only reconstruction, and (b) abundance weighted, raw counts based reconstruction.	186
Figure 6.24. First two components of PCA on the GUS modern pitfall trap data, showing species names.	186
Figure 6.25. First two components of PCA on the GUS modern pitfall trap data, showing vegetation/sampling zones.	187
Figure 6.26. Map of sites used in the 20 000 ^{14}C year reconstruction, see Table 6.15 for site names and time slices. The positions of the numbers in the call-out bubbles show the approximate position of the respective site symbols (+) on the map.	189
Figure 6.27. Plot of latitudes of sites in the 20 000 ^{14}C year reconstruction, per time slice.	190
Figure 6.28. MCR temperature reconstruction for the last 20 000 ^{14}C in 1 000 year slices using all European ^{14}C dated stratigraphic sequence samples in BugsCEP (Greenland excluded). (a) Bars represent the possible range of temperatures as indicated by the beetle faunas, for TMax and TMin; (b) the percentage of species in the area of maximum overlap from which the MCR values are calculated; (c) number of taxa (thick black bars), and individuals (thin grey bars) used in the reconstruction.	194
Figure 6.29. Jackknife results from 20ka temperature reconstruction, showing (a) the maximum (black extension bars) enlargement, and reduction (white boxes) of combined envelopes caused by the removal of any one taxa. The standard MCR values are shown as in Figure 6.28a. (b) shows the percentage of taxa whose removal causes a change in the reconstructed temperature range.	196
Figure 6.30. Climate space maps for time slice 14-15K, showing percentage overlaps for (a) all taxa, and (b) with <i>Boreaphilus henningianus</i> Sahl. excluded, the thermal envelope of which is outlined and shown in bold. The cells with maximum overlap, which make up the mutual climatic range are shown with white text on black cells. Note how the removal of <i>B. henningianus</i> creates a discontinuous area of maximum overlap, the outer limits of which give the MCR temperature values. This illustrates a potentially split fauna.	197
Figure 6.31. Graphs showing relationships, in the 20 ka dataset, between (a) the number of MCR species and the percentage of species whose removal leads to a change in temperature values; and (b) the number of taxa and number of individuals for the MCR subset and full dataset.	199
Figure 6.32. BugStats EcoFigs for the last 20 ka in 1 000 year slices, using taxa data only, (a) using all taxa, and (b) species identifications only.	202

List of tables

Table 1.1. Typical layout of a Quaternary data cross-tabulation, referred to as <i>countsheets</i> in BugsCEP and this thesis.	3
Table 2.1. Summary of BugsCEP program features.	14
Table 2.2. The de-normalized central INDEX table in BugsCEP. The headers are field names, and the rows are records.	19
Table 2.3. Hypothetical section of a more normalized version of the BugsCEP index table. UID = Unique Identifier, the key field for this table. The AUTHORITY field could theoretically be normalized further to remove empty cells by splitting it off into a separate table.	19
Table 3.1. Example of size data stored in the measurable attributes table.	35
Table 3.2. Bibliography table fields, with example.	36
Table 3.3. Two biology records for the water beetle <i>Ilybius vittiger</i> (Gyll.).	37
Table 3.4. Available sample date range and uncertainty flags.	42
Table 3.5. Summary of BugsCEP data, showing number of records per data area (support tables excluded).	43
Table 3.6. Physical disk space size of BugsCEP database (see text for disclaimer).	43
Table 3.7. Available countsheet context descriptions and enumeration in BugsCEP.	45
Table 3.8. International distribution of known Bugs users.	50
Table 3.9. A summary of the BugsCEP main interface areas. I/O = Input/Output.	51
Table 3.10. Red Data Book classification systems available in BugsCEP.	57
Table 3.11. Basic outline of the ecology classification systems used in BugsCEP.	59
Table 3.12. Outline of standardization options in BugStats.	74
Table 3.13. Extract of the numerical results output for the thermal reconstruction from the Saint Bees site, using the 'Closest to 100%' option. See Table 3.14 for an explanation of column headers.	81
Table 3.14. Explanation of MCR results terms, see Chapter 5 for more details on the method. All results are in degree Celcius.	81
Table 3.15. Data areas currently searchable with the Bugs Search Explorer, along with the method of criteria specification.	84
Table 4.1. List of Bugs EcoCodes, with diagram label and short description. Indicator classes are in <i>italics</i> , and * marked classes represent narrow habitats. See text for further explanation.	102
Table 4.2. Comparison of the habitat codes ascribed to a eurytopic and a stenotopic genus. Note that the apparent degree of stenotopy is a direct function of the code system as well as the ecology of the species.	103
Table 4.3. Koch (1989-92) ecology classifications as implemented in BugsCEP. Translation provided by Paul Buckland, assisted by Eva Panagiotakopulu. Classes in bold were added by the translators to improve the usefulness of the system in archaeology.	117
Table 5.1. Explanation of MCR results terms, repeated from Chapter 3. See chapters 3 and 6 for worked examples and outputs. The reconstructed temperature range limits are collectively referred to as TValues.	121
Table 5.2. Species list return from Predictions module when searching for species with TMin and TMax spans equal to or narrower than <i>Diacheila arctica</i> (Gyll.).	128
Table 5.3. List of species, and their thermal tolerance extremes, which have TMax ranges equal to or narrower than 7-14°C. Species that would not be able to cope with an increase in summer temperature ranges of 2°C are in bold	129
Table 5.4. List of species, and their thermal tolerance extremes, which have TMax ranges equal to or narrower than 9-16°C. Stenothermic species that would not have been able to survive a 2°C lower TMax value are in bold	130
Table 5.5. Warm/Cold reference cells used in RECON. Reproduced from Perry (1986:131).	134
Table 5.6. Jackknife statistics for sample s50, Saint Bees (Coope & Joachim, 1980), calculated from the results shown in Table 5.7. See Table 5.8 for more details.	136
Table 5.7. Jackknife process output for sample s50, Saint Bees site, slightly modified as follows: Species whose removal causes a change in the TValues are in <i>italics</i> ; species whose removal leads to a 100 % overlap area are in bold	138
Table 5.8. Statistics calculated by the BugsMCR jackknife routine.	139
Table 6.1. Sampled landscape units summarized from Koivula <i>et al.</i> (2004)	143
Table 6.2. Modified Sørensen's coefficient of similarity (Southwood, 1978), showing slightly closer similarity between the Edge fauna and the Farmland fauna, than the Edge fauna and the Forest fauna.	147
Table 6.3. MCR thermal reconstruction for Koivula <i>et al.</i> (2004) reconstructed grouped trap data. All groups produced 100 % overlap regions. Present day climate for southern Finland given for comparison. See Chapter 5 for explanations of the reconstruction method and variables.	148
Table 6.4. Comparison of number of species per group/classification. Note that BugStats allows species to fall into more than one class.	149

Table 6.5. Comparison of Ponel's ecological requirement categories and Bugs EcoCode equivalents. Bugs EcoCodes that are not directly equivalent to Ponel classes are shown in <i>italics</i> .	151
Table 6.6. Correlation matrix showing modified Sørensen's coefficient (Southwood, 1978) between La Grande Pile samples. Darker shading represents greater similarity between sample pairs, and coefficient values are on a scale from 0 = no similarity, to 1 = total similarity.	161
Table 6.7. Hemavan – processed sample depths and descriptions. Sample depths are in cm.	168
Table 6.8. Beetle species list from Hemavan (continued on next page).	169
Table 6.9. Thermal limits for species in Hemavan bottom sample 145-160cm. See Chapter 5 for explanation of variables.	173
Table 6.10. Beetle species from Lockarp 7B feature 14495.	177
Table 6.11. Beetle species from Lockarp 7B feature 26551.	178
Table 6.12. Summary counts and sums for the Lockarp 7B 'wells'.	181
Table 6.13. GUS modern, vegetation zone field descriptions.	184
Table 6.14. GUS modern species list, zone abundance sums for the four week collection period.	185
Table 6.15. List of sites used in the 20 000 ¹⁴ C year, 1 000 year time slice reconstruction, indicating the time slices for which each site has ¹⁴ C dated samples. Note the absence of time slices 18-17K, 17-16K and 16-15K which produced no data. See BugsCEP for references for all sites.	190
Table 6.16. Summary of samples and species occurrences from 1 000 year time slices for the past 20 000 ¹⁴ C years. An 'occurrence' is a fossil record of a specific taxon in a specific sample, and may either be an abundance or presence value, see Table 6.16 for more details. Note the important difference between the number of taxa (NSpec), and the number of taxa available for MCR (No. MCR Taxa).	192
Table 6.17. Explanation of cell and total values in Table 6.16.	193
Table 6.18. Modified Sørensen (Southwood, 1978) correlation coefficients comparing 1 000 year time slices for the past 20 000 years. Note that the full dataset has been used, and not just the MCR species, and time slices with no data have been omitted.	200
Table 6.19. The effect of standardization (Std) on the relationship between <i>sample habitat sums</i> and <i>the numbers of species in samples</i> (species level identifications only). Values are R ² , the Pearson product moment correlation coefficient, indicating the proportion of the variance in the habitat class values that is attributable to variance in the numbers of species. Values are shaded by magnitude, and a higher value indicates greater correlation.	203
Table 6.20. Amount of variance per habitat group explained by the different temperature values output from BugsMCR. Cell values are R ² , and <u>underlined</u> numbers indicate negative relationships. TMaxDiff and TMinDiff are the TMax and TMin spans respectively (e.g. TMaxHi-TMaxLo). Cells are shaded by R ² value, see the text for explanation of the bold highlighted cells.	205

List of abbreviations

Bugs	– A general reference to any version of the software created in the Bugs project, concerning the long-term development of a database for palaeoentomology.
BugsCEP	– The latest version of the Bugs software, the Bugs Coleopteran Ecology Package.
BugsMCR	– The climate reconstruction component of the BugsCEP software.
BugStats	– The environmental reconstruction and statistics component of the BugsCEP software.
GIS	– Geographical Information Systems.
(G)UI	– (Graphical) User Interface.
MAL	– Environmental Archaeology Lab, Umeå University (Miljöarkeologiska Laboratoriet).
MS	– Microsoft.
(R)DBMS	– (Relational) Database Management System, a software package for developing and/or administrating databases.
SQL	– Structured Query Language – a common language for database data retrieval.
VBA	– Microsoft's Visual Basic for Applications programming language.

Database terminology

Database	– A collection of related data items, and the information describing them.
Table	– A subset of the database, containing records and fields of more closely related data.
Record	– An individual row of related data in a table.
Field	– A column in a table, where each record/field cell contains the value of the field for that record.
Key Field	– or Primary Key – a field that holds unique data that can be used to identify any record in the table.
Index	– Generally a sorted field in a table, allowing records to be arranged according to some defined sort order such as ascending/descending.
Query	– The database name for a request for specific data from the database. SQL is a type of language for writing these requests.
Backend	– The actual data part of the system, stored on the user's machine or a server.
Frontend	– The software used to interface the data (backend), stored on the computers of individual users, but could also be accessed through a web browser.

General terminology

In any multidisciplinary project there is inevitably a potential risk for the mixing of terminology, and this thesis is particularly at risk by drawing from areas of Quaternary science, ecology, archaeology, geography, computer science and software development. I have tried my best to be consistent by using the definitions favoured by Quaternary science and the consumer end of software development. The former is itself an implicitly multidisciplinary field, and thus has evolved a language which is common to the majority of those who work with the study of human interactions with the environment, including archaeologists. By leaning towards the consumer end of software development the intention was to limit the use of technical development and systems analysis terminology, that is to say, use words that the majority of only slightly computer literate readers should be able to understand. On a similar theme, the use of applied statistical terminology could cause confusion due to the duplication of terms, primarily related to sampling in archaeology and Quaternary geology. The following definitions should aid clarity.

The word "site" is used in its archaeological and palaeoecological definition, as the location of a sampling activity. For example: an archaeological excavation; a lake or peat bog where samples have been taken. Note that this is not the definition used by Jongman *et al.* (1995).

The word "sample" is used in its archaeological and palaeoecological definition, as the actual physical unit of analysis within a core or from a site. For example: a five centimetre high, five litre block from a peat bog, which is part of a column of samples (see Hemavan example in Chapter 6); a one centimetre slice from a lake core; the contents of a bowl excavated from a Norse Farm in Greenland. Note that this is not the statistician's definition of a sample, but sometimes overlaps this.

The terms "clustering" has been used as in Jongman *et al.* (1995), to describe the grouping of points, be they species, samples or sites as defined above. "Classification" has been used synonymously to describe the process of assigning species to specific habitat groups, and the habitat groups occupied by a species. The distinction has been made between *habitat groups (or types)* as definitions of a particular environment or biotype from its physical and vegetative properties (e.g. wetland, dung), and *species groups*, or what Eyre & Luff (1990), among others, call '*habitat groups*' – species groupings that have been compiled through statistical analysis. This is a particularly important distinction to bear in mind when reading Chapter 4.

Although several parts of this thesis discuss statistics, the use of terminology from the field has been limited, as it tends to be at a tangent to palaeoecology terminology. As the latter becomes more and more saturated with quantitative methods, however, this is becoming less the case.

Where the software is described, on-screen buttons to be pressed have been placed in square brackets: [Button], whereas keyboard key presses are indicated by enclosing less than/greater than signs: <F1>.

Database field names are referred to in the case that they have in the database structure, i.e. ‘taxonomic CODE’ refers to the ‘CODE’ field in the database, whereas ‘taxonomic code’ refers to a taxonomy coding system independent of the database.

When a species name is mentioned for the first time in a section it is written in full, whereas the genus is abbreviated on subsequent mentions, e.g. *Carabus nemoralis* Müll. and *C. nemoralis* Müll. This convention is broken when its use could lead to confusion, and when a reasonable amount of text has passed between uses. Authorities (the abbreviated name following the species) are always given to avoid taxonomic misunderstandings, but may have been omitted from a few tables where space was limiting.

A number of aspects discussed are relevant to both palaeo and modern studies. Where this requires emphasis, the ‘palaeo’ prefix has been bracketed, as in ‘(palaeo)ecology’. Similarly, where both quantitative and semi-quantitative methods are implied, the form ‘(semi-)quantitative’ has been used.

The structure of the thesis

This thesis by no means follows the traditional structure of a Faculty of Arts work. The combination of software development, which entails an amount of developmental and descriptive text, along with methodological development and then application of the techniques has lead to a three part structure, distributed through six chapters.

After the introduction (Chapter 1), there follows in Chapter 2 an account of the development of the Bugs Coleopteran Ecology Package (BugsCEP), including a discussion of the realization of project goals, and a brief developmental history. Although this chapter may appear to be of little interest for many readers, it but puts the rest of the work in perspective.

Chapter 3 goes on to describe first the data within BugsCEP, and then the software tools which have been programmed to allow the entry and use of these data. The necessity of various aspects of the data are discussed, and practical instructions given as to the use of the software, with examples where relevant. This chapter also introduces the sub-components of BugsCEP: BugStats and BugsMCR, which are described in more detail in the subsequent two chapters. Chapter 4 describes the BugStats environmental/habitat reconstruction and statistics software component, putting it in the context of previous work and explaining the methods used in detail. Chapter 5 explains the implementation of the Mutual Climatic Range (MCR) method for climate reconstruction in the BugsMCR software component, explaining some of the refinements made and possibilities for future enhancements.

Chapter 6, which precedes the final conclusions, applies the software described in the earlier chapters to practical examples. The data used in this chapter are a combination of work by myself and work published by others. This chapter may be of most interest to the general reader, although reference to earlier chapters is recommended for a more complete understanding of the methods used.

Acknowledgements

I came to Sweden in 1996 seeking adventure and a PhD. Adventures soon followed, but the PhD didn’t progress quite as quickly as I originally intended, but now, more than ten years later the thesis is finished. My primary goal has always been the further development of the Bugs software, which may explain why parts of the thesis are somewhat like a manual. In the original PhD proposal, the software development was to be combined with my own palaeoentomological investigations into past environmental and climate changes in Sweden, preferably along two transects in the north of Sweden. It became evident, however, at an unfortunately late date, that the simultaneous development of the software and comprehensive lab-based analyses was infeasible. As a result, there are only three and a bit of my own sites included in this thesis. The addictive nature of software development is perhaps a

course designed to prevent developers from ever having much time to really use their software. There is always ‘just one more function’ that can be added, and a number of the tools found in BugsCEP are the result of this. As curses go, I don’t think it was such bad one, and I think the release of a cohesive software package is an important part of this work. Besides, I am reasonably pleased with the release version... for now.

BugsCEP and this thesis would, of course, not have been possible without the help of a large number of other people. Paul Buckland, my father, as the co-founder of Bugs along with Jon Sadler back in the 1980s, deserves a special mention. Without his ideas, encouragement and continual addition of data, the software would never have become such a comprehensive package. I am also certain that his reputation has helped me to do many an interesting thing in the name of science – and that includes white water rafting in Greenland. Yuan Zhuo Don, who programmed the first successful MS Windows version of Bugs, may be solely responsible for tuning me in to the power of MS Visual Basic, and its ability to work in tandem with MS Office. Even with effective tools, development is not always easy, and members of the tek-tips.com forum have repeatedly helped me through programming or database troubles over the past years. Good software rarely gets produced without rigorous testing, and Malcolm Greenwood, Fredrik Olsson, Eva Panagiotakopulu and Nicki Whitehouse have been especially forthcoming with comments on various bits of BugsCEP. Eva has long been supportive of the Bugs work and contributed significantly to EgBugs, and Fredrik in particular became an avid tester of the BugStats component. Geoffrey Lemdahl, my unofficial external supervisor in the latter part of the PhD, provided many useful suggestions and the preliminary identifications from Njulla. Frank Köhler was kind enough to provide me with a copy of the German Coleoptera database, which proved invaluable in sorting out a number of taxonomic problems. My father, Paul, and fiancé Tina have helped considerably in making the thesis more understandable, and both worked hard to ‘deswenglify’ it. I am also most grateful to Sheila Hicks, who has repeatedly made the time to discuss various aspects of the thesis, science and life with me during our somewhat random encounters. BugsCEP would, of course, be nothing without its data, and although there is no room to thank well over 1 000 authors here, a short thank you list is on the website www.bugscep.com. I’m sorry if I have missed anyone, but please send me an email and I’ll add you to the website!

Despite many fine words, funding for interdisciplinary research is much harder to find than for single science studies. I have been fortunate enough to have my PhD position funded by The Bank of Sweden Tercentenary Foundation, under the Northern Crossroads project, and this, together with a number of smaller European Science Foundation and Faculty of Arts grants have made it all possible. My parents and Grandfather also financed several trips to the UK, for which I am eternally grateful. Matti Koivula and Philippe Ponel kindly permitted me to use their data in the thesis case studies, and Peter Rosén worked hard to obtain and help process the, as yet unfinished, Njulla cores.

As a PhD student I have had the opportunity to study a number of external courses, and three of these proved particular fruitful. Firstly, ‘Biostatistics’ at EMG, Umeå, after which Tom Korsman suggested the multiple removal jackknife technique. Secondly, ‘Jackknifing and bootstrapping with applications’ at SLU, Umeå, and especially the discussions with Magnus Ekström on the use of jackknifing with MCR. Finally, the ESF HOLIVAR ‘Quantitative climate reconstruction and data-model comparisons’ course at UCL, London, which provided much inspiration. I’m a firm believer in never working within disciplinary boundaries, and the Environmental Archaeology Lab, Umeå, has not only provided an atmosphere conducive to this theme, but also colleagues and friends that have supported me through the years in a land that was supposed to be full of Vikings, but apparently isn’t. They have even helped me to learn a language where the words for ‘lizard’ and ‘cultivate’ are only an umlaut apart. Foremost of these individuals is my supervisor Roger Engelman, a true multi-disciplinarian, who has given me the freedom to wander a somewhat free-range course towards the conclusion of this thesis, just in time for his retirement. Johans L and O have also provided many a feedback session, even if it took them a bit too long to understand that a computer cannot properly function with less than two monitors. In addition, Carolina, Helena, Jan-Erik, Karin, Nina, Sara, Sofia and Åsa have all been great company and provided many cakes. Although my research has been somewhat confusing to many at the department of Archaeology and Sámi studies, Umeå, the engagement of staff and other PhD students in seminars and discussions has provided a considerable amount of help and inspiration. Also, we the

PhD students have had our troubles, and I'm very grateful for the mutual support that we have managed to maintain as a doktorand group, Birgitta probably having put more effort into keeping things going than most of us.

I've made a number of very good friends in Sweden, a surprisingly large number of whom seem to understand why somebody would want to remain a student for the equivalent of nine years. There are also a few of them who understand Neil Innes' famed words, "I've suffered for my music, now it's your turn", better than most. Just wait till the Hammond arrives. Anders, Brendan, Janne, Johan O, and PJ – you know who you are. Just for old times sake, Claudia, Markus, Patrick, Sofia and a number of others without whom the little town of Umeå would have been far less fun! Last, but never least, I'd like to thank my family (change camera angle), for their constant support during my studies and adventures in the Arctic wastes. Without my mother, Joan, Dad would never have been able to maintain his enthusiasm for beetle work, as a man is not able to live on cheese on toast alone. She has also constantly supported me in my wanderings. Rob (Bro) deserves some kind of thanks for periodically bombarding me with inane web links, and cute pictures of his kids. In the grand tradition of saving the best to last, I'd like to say at least eleventy million thank yous to Tina, who is without a doubt the best sweetheart in the world! :)

“In this great future, you can’t forget your past”

(No woman, no cry)

Bob Marley – musician, Rastafarian, and so it would seem, Quaternary scientist.

“I’ve suffered for my music, now it’s your turn”

(The Idiot Song, live)

Neil Innes – musician, comedian, and unknowing writer of the above one line PhD summary.



Dedicated to Penguins everywhere.

1 Introduction

1.1 Aims of the Thesis

The work behind this thesis is essentially that of methodological development – more specifically the development of software to act as a research and teaching tool for palaeoentomology and ecology. BugsCEP, as the Bugs Coleopteran Ecology Package is abbreviated, has been developed to this end, and is described here along with a number of case studies and worked examples to illustrate its purpose and evaluate its usefulness. The analysis of fossil insect remains is a valuable method in the study of past environments and climates, and important in both environmental archaeology and Quaternary geology research. The software described here is developed in such a way as to also be of use to landscape ecologists, environmental scientists and entomologists. Whilst the database currently centres upon Coleoptera (beetles), it also provides a framework for expansion into other insect groups of use within palaeoecology and environmental archaeology such as Trichoptera (caddis flies) and Diptera (flies).

In addition to this general aim, the thesis project has a number of major sub-themes:

1. The development of a new relational version of the existing Bugs database. The Bugs2000 system (Buckland, 2000) was constructed around a somewhat inefficient database structure that did not fully implement the concept of relational database architecture. A restructuring provided massive improvements in the efficiency of data retrieval, updating and data security aspects of Bugs. It also allowed for the development of more advanced searching, querying and reporting tools which can take advantage of the improved architecture. These improvements essentially make up the core component of the BugsCEP software package, the development of which is described in Chapter 2. The system is described in full, with examples, in Chapter 3.
2. The construction of a system for (semi-)quantitative environmental reconstruction/habitat description from fossil insect remains, providing easily interpretable, and consistently comparable graphical outputs. This is based on an ecological summary system that uses the modern ecology of the organisms as its reference/calibration data, and the statistical methods employed are transparent and relatively simple. It provides facilities for compensating for unequal sample sizes and abundances, as are common in (palaeo)ecology. Inevitably, the methods employed are based on a number of existing classification and visualisation concepts, although they are provided here for the first time connected directly to a database of Coleopteran ecology and fossil records. This system, which makes up the BugStats package component, is described in Chapter 4.
3. The implementation, and enhancement of the Mutual Climatic Range (MCR) method (Atkinson *et al.*, 1986) for deriving palaeotemperatures from fossil beetle assemblages, as a component in Bugs. MCR was previously available only as either MS-DOS based software or by somewhat laborious, and error prone, manual overlaying of transparency films. A version running in a graphical (Windows) environment, as developed here, would have been a significant improvement in itself. The aim here was to improve the availability of the method, provide improved graphical outputs, and explore the possibilities for improving the accuracy or precision of the MCR method through statistical techniques. This amounts to the BugsMCR package component, which is described in Chapter 5.
4. The testing of the thermal and environmental reconstruction software, developed in connection with this thesis, on a number of datasets, including those from published modern and fossil studies, as well as those produced by the author specifically for this thesis. These studies are presented in Chapter 6.

In addition to these specific aims, the wider Bugs project also endeavours to:

5. Make the Coleopteran fossil record of Europe publicly available through a single, downloadable source: <http://www.bugscep.com>
6. Make the process of interpreting fossil insect remains more efficient, by reduce the time necessary for looking up biology and distribution data, and performing routine data compilation/summary tasks.
7. Provide a system for the recording and storage of species list and abundance data.

These latter points have been fundamental concepts behind all previous versions of Bugs, and the latest version, BugsCEP, improves on the work of these and adds many improvements.

1.2 Scientific Background

As with any piece of science, this work is a building block in a developmental history. Although the software created here contains a number of innovations, and is the first of its kind in many respects, its development owes a lot to those who have preceded it. Aside from the numerous previous versions of Bugs (which are briefly described in Chapter 2), there are other Quaternary databases in existence that have influenced the development. The statistical methods implemented in BugsCEP (MCR, jackknifing, environmental reconstruction and coefficients of correlation) contain both original, derived and applied components.

Although the collation and storage of Quaternary entomology data was computerised relatively early (Sadler *et al.*, 1992), the development and application of quantitative methods to fossil beetle data have lagged behind some other proxy data fields. Palynologists, for example, have developed advanced numerical methods for landscape reconstruction from pollen assemblages (e.g. Sugita *et al.*, 1999). Although most authors routinely include summary statistics for numbers of beetle taxa and individuals in publications, very few attempt quantitative environmental reconstructions.

1.2.1 Databases in Quaternary science

The generally large datasets of Quaternary science make it an ideal subject for database construction. For each site within a project there may be several sampling locations (e.g. boreholes, cores, archaeological features/structures) which can result in numerous samples, for each of which there will be abundance data for any number of species (Figure 1.1). It is easy to see, then, that the individual data items can quickly amount to hundreds or thousands depending on the proxy type and preservation within the samples. Several Quaternary databases are available, perhaps the most widely used proxies being pollen and vertebrates (e.g. EPD, FAUNMAP, see section 1.2.4).

The scope for variation in abundance is enormous. This is not only a product of the natural diversity of organisms in differing environments, but a combination of this and sampling and other taphonomic factors. For example, the (early-mid Holocene) medium diversity, low abundance site of Hemavan, Sweden, analysed in this thesis (see Chapter 6) has ten samples, 61 species and 119 abundance counts. The (Lateglacial) high diversity, variable abundance site of Saint Bees in Cumbria, England, (Coope & Joachim, 1980) is made up of 35 samples, 283 species and 1 363 abundance values. These numbers are small when compared to those encountered in pollen analyses, where the microscopic nature of grains and spores and the relative ease of identification allow for much larger quantifications. The quantities, and the variations in them, are of course extremely important in the interpretation of samples, and especially when considering the relative reliability of reconstructions based on those samples. This is discussed in more detail in Chapter 4 with particular reference to quantitative methods. An enumeration of the numbers of data items in BugsCEP can be found in Chapter 3.

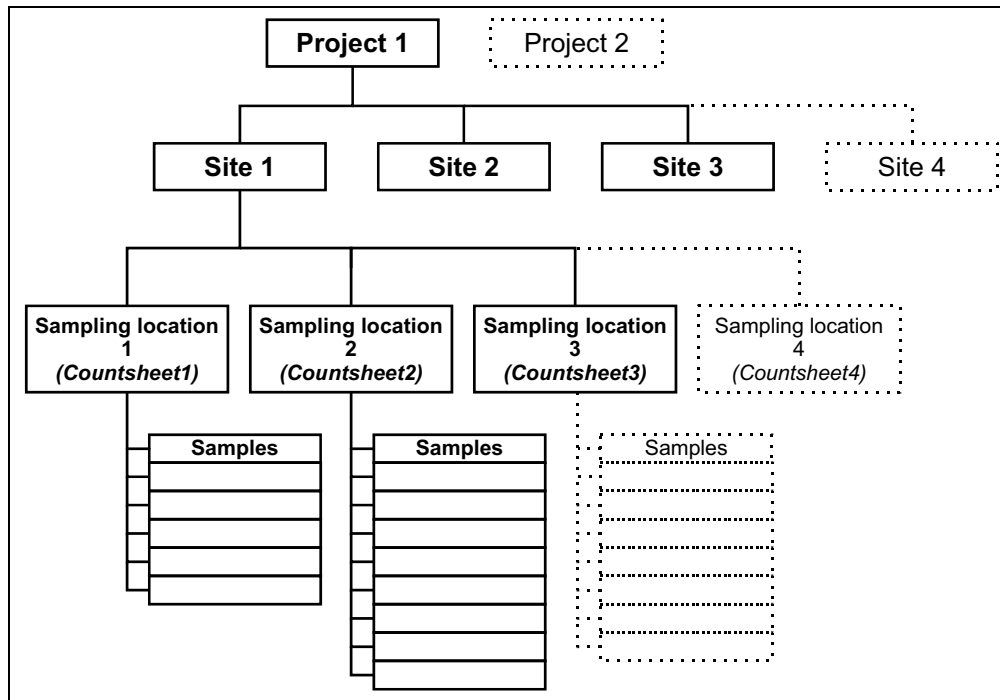


Figure 1.1. Typical Quaternary science sample hierarchy from project to sample level. *Italics* show where the BugsCEP name differs from the common usage. A sample contains abundance data for each species found in it (see Table 1.1).

1.2.1.1 General Quaternary data structure

The vast majority of Quaternary data can be displayed using a simple cross-tabulation (crosstab) of species against samples as shown in Table 1.1. Abundance counts, or the number of individuals, are recorded for the occurrence of each species in each sample. In the majority of fossil insect works, these are usually the minimum number of individuals (MNI) represented by the fossil exoskeleton parts (sclerites) found. Although the crosstab structure is an easily understandable form for humans, it is inefficient for data storage due to the potential for empty, or zero abundance cells, which create dead space in the table. In a database management system (DBMS) this generally not only leads to an increase in file sizes, but also breaks some of the guidelines for relational database structure. The implications of this for the efficiency of data retrieval are considerable, and although BugsCEP displays abundance data in crosstab form, it stores it in a more efficient manner, the mechanics of which are described in section 3.1.3.

Table 1.1. Typical layout of a Quaternary data cross-tabulation, referred to as *countsheets* in BugsCEP and this thesis.

Site Name				
	Sample 1	Sample 2	Sample 3	...Sample n
Species A	abundances			
Species B				
Species C				
...Species z				

1.2.2 The BugsCEP structure in brief

The BugsCEP software is more than just a database in that it has a large number of custom built interfaces for data entry, retrieval and manipulation. These interfaces, along with the code and other objects behind them, collectively make up the *application* or *program* part of the Bugs Coleopteran Ecology Package. The other part contains the actual data, and is what is commonly referred to as a

database. In fact, these two parts are separate files in the BugsCEP package, BugsCEP.mdb and bugsdata.mdb, and are often referred to as the *frontend* and *backend* respectively (see also section 2.2.2). The *frontend* is the part that the user interacts with, which itself interacts with the *backend* in order to fulfil the user's requests. Inevitably the functionality and quality of the *frontend* dictates how easily users can access the data. A good *frontend* will be transparent, in that the user will hardly be aware of the physical structure of the database, and user friendly, eliminating the need for knowledge of Structured Query Language (SQL) or general database skills.

1.2.3 What is BugsCEP and what does it replace?

Prior to the development of the initial concept of a Quaternary entomology database by Sadler *et al.* (1992), correlation of ecological, distributional and fossil data relied either upon the personal knowledge of the researcher or upon extensive literature searches, sometimes extracted onto a card index. Bugs initially supplemented, and later significantly reduced, reference literature searches by abstracting the most important bits of text describing the biology and distribution of species into a database. Thus a researcher could access a large part of the information needed to at least begin interpreting fossil beetle assemblages rapidly from a computer system, rather than having to use the library and thumb through books and articles. Although BugsCEP includes enough data to come a long way in interpretation, reference to the original papers is still recommended for detailed aspects of species ecology. In addition, for work in some countries, the geographical range of the source literature for a number of species is not yet extensive enough for the system to be completely independent of external literature.

The original concept of the database has been further developed to include climate and environment reconstruction, statistics, and comprehensive data management facilities. Some of these facilities were previously only available through the use of additional software, or through manual calculations.

1.2.4 Related databases

There is currently no existing system comparable with BugsCEP in terms of the scope its data and the features it provides. BugsCEP is not only a database of fossil sites and their abundance data, but also a database of modern biology, distribution and bibliographic data among other things (see Chapter 3). In addition, it includes a number of tools for climate and environmental reconstruction, and data management the likes of which are not found in any other single database system for any other proxy. This integration of a software package and a reference database for modern and fossil data is currently unique, but similar systems are in development (see e.g. SEAD below).

The list of existing and planned databases below is in no way exhaustive, and is only intended to direct the reader towards some important resources. Databases with limited regional and subject scope have been excluded, although there are a number of interesting databases with web interfaces available. There are also a number modern ecology and habitat databases that could be of use to Quaternary scientists, but contain no Quaternary data in themselves (e.g. EUNIS biodiversity database, Ground Beetles of Irelandⁱ). A number of the databases below, in addition to BugsCEP, are available from the NOAA Paleoclimatology website at <http://www.ncdc.noaa.gov/paleo/paleo.html>, which is part of the World Data Center Systemⁱⁱ repository for scientific data.

EDDI - European Diatom Database

<http://craticula.ncl.ac.uk/Eddi/>

A web based system including a variety of diatom datasets, training sets and transfer functions to aid in environmental reconstruction from lake deposits. Data have been collated from a large number of

ⁱ EUNIS: <http://eunis.finsiel.ro/eunis/>; Ground Beetles of Ireland: <http://www.habitas.org.uk/groundbeetles/>

ⁱⁱ <http://www.ngdc.noaa.gov/wdc/wdcmain.html>

sources, and a large number of images are included. The system also allows users to see distribution maps online, and upload data for reconstruction of pH, conductivity and other variables by a variety of methods. Software is available for download which is compatible with the online database.

EPD – European Pollen Database (and other regional equivalents)

http://www.ncdc.noaa.gov/paleo/epd/epd_main.html

Although it contains no ecological reference data, the EPD deserves a mention as one of the most widely used Quaternary databases in existence. The database provides geographical metadata, bibliographic information and raw data for a considerable number of palynological investigations throughout Europe. Related projects include equivalent data for Africa, Canada, and North America (NAPD) and South America, in addition to a Global Pollen Database (GPD). Some facility for the storage of other plant macrofossil data is built in to the structure, although the latter is under revision at the time of writing. Some of the data are available online through map (WebMapperⁱⁱⁱ) and query based search engines, although without an integrated GIS functionality. It is also possible to download the EPD as database tables, to which an SQL interface is available on request. Related projects include regionally specific climatic, landscape and ecological calibration data. A variety of external statistical and graphical tools are available for pollen data (e.g. Tilia and TiliaGraph, C2^{iv}).

ADS – Archaeological Data Service

<http://ads.ahds.ac.uk/>

This UK based large scale database project contains an enormous amount of archaeological data, but only a limited amount of environmental archaeological data. The latter datasets vary in form, and can only be queried at the metadata level. That is to say it is possible to find sites with environmental data, but individual site datasets must be extracted in order to undertake further analyses. There is great potential for the integration of environmental and archaeological datasets into the search system. No modern reference data is included, and only a limited amount of environmental proxy data is available.

FAUNMAP - late Quaternary distribution of mammal species in the United States

<http://www.ncdc.noaa.gov/paleo/fauna.html>

Funded by the US National Science Foundation, FAUNMAP includes data from about 2 919 sites spanning the last 40 000 years. The database was created to map the past distribution of mammals with an aim towards providing increased understanding of the evolution of mammalian communities. The system is accessible online, and includes search and GIS (map) interfaces for data from archaeological and palaeontological sites. The database is also intended to aid in palaeoenvironmental reconstruction, especially when combined with other geographically based proxy data. A number of international regional versions of the database exist.

SEAD – Strategic Environmental Archaeology Database

<http://www.sead.se/> (Buckland *et al.*, 2006)

Currently in the early stages of construction, SEAD is designed as a multiproxy database system for the storage and analysis of data primarily relating to environmental archaeological investigations. The system includes the ability to store large amounts of site based metadata, bibliographies and ecological reference data along with project management data. It is designed to handle a number of proxy data sources including insects, pollen, molluscs, soil properties and plant macrofossils. The initial version will be limited to Swedish data, and it will eventually be available both online and through local client interfaces. SEAD is currently under development at the Environmental Archaeology Lab, Umeå

ⁱⁱⁱ <http://www.ncdc.noaa.gov/paleo/webmapper.html>

^{iv} Tilia: <http://www.ncdc.noaa.gov/paleo/tiliafaq.html> or <http://museum.state.il.us/pub/grimm/> ;

C2: <http://www.campus.ncl.ac.uk/staff/Stephen.Juggins/software/c2home.htm> (not only pollen data)

University in Sweden. The author of this thesis is the lead developer in the SEAD project, and large parts of its interface and structure are derived from those in BugsCEP.

LNED – Late Neogene Ecosystems Database (working name)

In its early stages, LNED represents a consortium of American Quaternary scientists and environmental archaeologists working towards a unifying database of biological proxy sources. The LNED team are working with a number of the representatives of the other databases mentioned in this section to create either a single database, or series of linked databases, that would first encompass the American data, and then be expanded to include global data. In achieving this, the system will then be used as the basis for developing tools which will enable the advanced, multi-proxy querying of data in terms of climate and environmental changes over varying timescales.

1.2.5 Taxonomy and fossils

The binomial system of taxonomy, initially systematized by Carl von Linné (Linnaeus) (Knapp, 2000) provides the necessary baseline for any ecological or palaeoecological study which employs plant or animal data. Its purpose is to divide the animal and plant kingdom up into manageable units, previously by division on morphology, but more recently by genetic similarity. Morphological distinctions are extremely useful in the differentiation of fossil fragments, and a modern reference collection arranged in taxonomic order is indispensable when identifying fragments, as similar species are generally close to each other in the collection. Genetic distinctions, on the other hand, are currently of little use in palaeoecology due to the poor preservation of DNA and the time and cost that would be involved in getting DNA work done on every difficult fragment. Names have been often revised, especially since the advent of DNA techniques which have revealed numerous groupings to be incorrect, and there is thus a synonymy associated with the majority of current species names which allows for reference of the same species under various names throughout history. Statement of the taxonomic system followed in a database is therefore essential, and a list of synonyms practical, if it is to be useful internationally and in several fields. Most countries have their own taxonomic systems, which are usually similar to each other, but reflect the local faunas and the history of regional entomology to an extent. There are Internet based systems in development, such as the Global Biodiversity Information Facility (GBIF, 2006) which are aimed at uniting, or at least meshing, national systems and providing an international node for taxonomic information, including data on the availability of reference specimens in museums.

BugsCEP uses a taxonomy based upon Lucht (1987) as revised by Böhme (2005), and Gustafsson (2005) (with changes where noted), and with some revision at the family and subfamily level, according to Lawrence & Newton (1995). Taxonomic codes, a modified form of the Central European Codes of Lucht (1987), are used throughout the database to provide a unique numerical identifier to every taxon, and provide the taxonomic order.

Species are not always fully identifiable as fossils, either because of poor preservation masking characters necessary for splitting between species, or because some species simply are not identifiable to species level on the individual parts that are found fossil (most commonly the head, thorax and elytra). The latter varies between groups, with genera smaller in size being generally more difficult to identify. The skill of the individual researcher and access to modern reference collections, for comparative material, are also a factor. BugsCEP includes a number of taxon records that reflect these difficulties, and others for particularly difficult species. Almost every genus is ended with ‘sp.’ (species) and ‘spp.’ (species plural) records which can be used to record individuals identified to generic level, as can the ‘indet.’ (indeterminate) records that exist for some more difficult families. In addition, there are a number of doublets for commonly hard to split species, such as *Nebria brevicollis/salina* (F.)/Fairm. & Lab. – which indicates an individual identified as either the ground beetle *Nebria brevicollis* (F.) or *Nebria salina* Fairm. & Lab. Finally, there are particular groups (grp.) of species that are hard to resolve, such as the mould beetles group *Latridius minutus* (grp.) (L.), which includes the species *L. pseudominutus* (Strand), *L. anthracinus* (Mann.) and *L. minutus* (L.).

The interpretive implications of all of the above are not always simple, although the level of detail in environmental reconstruction is usually reduced with lower taxonomic resolutions. The size of the genera, but more importantly the amount of variation in species habits and ecological preferences within the genera, affect how useful a generic level identification is. For example, a generic identification of the water beetle *Agabus* sp. can tell us that there was probably water close by, but not whether it was likely to be running or standing water, whereas the identification of *Agabus paludosus* (F.) is almost definitely an indication of running water (Nilsson & Holmen, 1995). Interpretive aspects will be discussed further in Chapter 4, along with the use of coded habitat descriptions.

1.2.6 The archaeological and contemporary contexts

This thesis is not what would currently be called a piece of traditional archaeological work, and some archaeologists would perhaps not even class it as archaeology at all. Environmental archaeology is a broader form of the archaeology discipline that is inherently multidisciplinary, and draws on methodology from numerous fields of science. It is also largely an empirical science, its practitioners generally requiring quantitative support for statements on the nature of the past. BugsCEP is, among other things, a tool for palaeoentomology, a science which can be extremely useful in providing data on past human activity and the natural environment. Under the right conditions, insect remains can be preserved in deposits on archaeological sites and in the sediments around them. The latter sediments are frequently overlooked or omitted from archaeological investigations to cut costs, but are extremely important for providing data to help understand the nature of the interactions between the occupants of a site and the environments around them. There are a considerable amount of data from archaeological sites in BugsCEP's database (see Chapter 3), and the software has the facilities for handling dating methods more typical of archaeological excavations, such as artefact typology and period designation, as well as radiometric methods more commonly used in Quaternary geology.

An understanding of the past environmental impacts of people is extremely important for policy decisions concerning sustainable development, the past being the key to the future. Similarly, investigations into the present day effects of human populations on biodiversity should always include an awareness of the long term past. An archaeological or geological component in research lines associated with these subject areas can provide important information on the probable consequences of planned actions if they have parallels in the past. Palaeoentomology, along with other proxy methods, can help by providing data on past environmental changes, and in combination with archaeological data provide evidence of the human component in these. It is becoming more common for Quaternary research to include an archaeological component, or at least an awareness of its importance, and the construction of databases with datasets and tools common to archaeology, Quaternary geology and biology are helping to bridge the gaps between these closely related research fields (and even occasionally influencing national policies^v). The Bugs EcoCode habitat classification system (see chapters 3 and 4), which was developed as part of this thesis, for example, has a specific class, *General synanthropic*, for species known to be found in close association with humans. It also includes a number of other classes that are particularly useful in describing past onsite (archaeological) activity: *Dung/foul habitats*, *Dry dead wood* and *Ectoparasites*. The last of these are almost only ever found fossil in archaeological deposits, due to the human habit of concentrating animals into small spaces and thus increasing both the potential for parasite survival and their deposition in preserving sediments. The use of this classification system in the analysis of 'natural' deposits, in collaboration with archaeologists, may help provide information on the probability of human influence in shaping the landscapes that lead to their deposition.

As well as the inclusion of archaeological groups in the Bugs EcoCode classification system, there are a large number of indirect relationships between the subject of this thesis and archaeology. Quaternary science and archaeology should be, and in fact have previously been intimately related. Many of the methods used in archaeology, such as dendrochronology, pollen analysis, radiocarbon dating and even the logic of stratigraphy were developed in Quaternary geology, and archaeologists would be hard

^v As the sudden government awareness of the importance of climate change has demonstrated (e.g. Stern, 2006).

pressed to achieve their goals without them. Although much archaeological work is site based, focussing on the deposits left behind by the people and animals that occupied a specific place, the data obtainable from archaeological sites have only a limited potential without knowledge of the surrounding environment, and the interaction of people with it. Activities from simply the gathering of firewood, to deforestation and farming all leave their signals in sediments in different ways, and at different scales. It is difficult to understand the past course of human activities at a site, and their impact on the surroundings, without an insight into the background conditions there. To understand these things we need empirical data from proxy sources – we cannot measure them directly, so we must rely on the examination of things that were there at the time to tell us about the concurrent conditions. It is simply not possible to stand in a present day landscape, and, by a process of imagination or projection, however ‘soundly based in theory’ it may be, obtain a reasonably accurate picture of any distant past form of that landscape.

To summarize, empirical data on past environments are essential for interpreting and understanding the history of human-nature interactions. Fossil beetles can provide us with excellent proxy data for these interactions, and BugsCEP is a tool that can help in the manipulation and interpretation of these data.