7 Conclusions

As the only available software package for the storage and analysis of fossil beetle data, with modern reference data included, it is difficult to compare BugsCEP with similar programs. The only alternative to using BugsCEP is the manual construction of species lists, ideally in spreadsheets, using checklists such as Gustafsson (2005) to provide the taxonomic order and synonymy. Ecology and distribution data can then be compiled for these lists by the use of published and unpublished literature and various Internet resources, the latter only recently becoming partly feasible, and the former requiring good library and museum collection access. Ecological classification of the species is often undertaken on the basis of specialist knowledge, although without a database it is difficult to be consistent between projects. The construction of diagrams similar to the Bugs EcoFig habitat reconstruction ones is laborious without semi-automated software assistance, and climate reconstruction through previous MS-DOS MCR packages, or by hand, is cumbersome. In addition to these improvements in efficiency, BugsCEP also provides a number of advanced search and query tools, such as rapidly obtaining the known fossil record for a species, which is extremely difficult to duplicate without the database.

The primary aims of the BugsCEP project have been fulfilled in this thesis, in terms of the restructuring of the database, and the implementation of climate and habitat reconstruction systems. As always, there is room for improvement, as there will always be with research orientated software, and a number of possibilities have been discussed throughout the thesis. In particular, some desirable functions are missing from this release of the software, the lack of Geographical Information System (GIS) functionality being perhaps the most important. Beetle distribution data are prime candidates for a geographical database, as are the location of fossil sites. The integration of point distribution data, climate data, and chronologically delimited fossil data would provide the foundations for an extremely useful investigative and modelling system. This is one of the primary directions for the future development of BugsCEP, and the research possibilities for GIS interrogation of the data are enormous. Before venturing into the world of GIS, however, one must be reminded of the data quality issues involved in drawing biogeographical conclusions from variably dated data. That is to say, one should be fully aware of the quality of dating evidence for every site that is involved in multi-site inferences, and the blanket application age depth models may confuse the results. One should also be aware of the implications of spatial variation of species presence between sites and dates. Taphonomic issues render ‘absence’ a very debatable concept – is a species not found because it did not live there, or because the sample size was too small, or because the sampling location did not provide a good trap for that species? These questions of sample representativeness are very hard to assess, and require a working knowledge of the ecology of the individual species and the depositional and preservational environment of the site. Suffice it say that multi-proxy analyses can be of great benefit in such situations – the additional proxies providing support information for the insect interpretations in terms of extra explanatory variables, and hopefully providing proxy information for some of the issues outlined above. BugsCEP provides an indication of the availability of that data, and could act as a starting point for assessing the availability of existing sites most suitable for detailed multi-proxy studies.

Little attempt has been made to address specific preservational and taphonomic issues here, and a detailed appraisal of the ecology of all species mentioned is beyond the scope of the thesis. The aim was more to provide some starting points for future research than to fully explore all angles in detail. BugsCEP includes a mixture of archaeological and other Quaternary sites, and it is important to be very careful when mixing these in large scale GIS analyses due to both the possible implications of human constructed environments, or human impact on the landscape, and the inevitable increased variability of preservation seen at archaeological sites. One could argue that the two groups of samples are not comparable (due to differences in sampling aims, standards and taphonomy), but as long as standard sampling and processing methodology has been followed then the identified faunas should be comparable, as long as the researcher is aware of the potential problems involved.

The successful implementation of BugStats, and the development of the Bugs EcoCode habitat classification system, is only the start of the possibilities for semi-quantitative environmental reconstruction from fossil beetle remains from the BugsCEP database. There are a number of theoretical issues that need to be investigated before the Bugs EcoFig system can be considered universally applicable. The primary concerns are, however, those that are common to any (semi-)quantitative reconstruction method, such as sample representativeness in terms of time exposure/collection, catchment complexity, the abundance and richness of species in the catchment habitats, deposit type (well, bog, pool, etc.), and the appropriateness of the numerical methods. These issues aside, the system does produce useful results which are comparable with those published independently by other researchers. Further testing, by a wider group of users, and on a wider range of contexts, especially modern references sites, is necessary for full validation of the method.

At the onset of this project, the intention was to create a system for assisting the refinement of species thermal envelopes, and even improve on the existing reference dataset. Although a prototype system was developed, using a combination of MS Access and ESRI ArcView 3.1 (Buckland & Buckland, 2002), the task proved far too time consuming to begin enhancing the envelopes within the scope of this project. The implementation of existing MCR dataset (Atkinson *et al.*, 1986), and the development of a new form of the temperature reconstruction software integrated with the BugsCEP site database proved successful and reliable. It also provided the basis for enhancements to the method which may prove suitable for refining the climate reconstructions made from fossil beetles.

7.1 Wider Applications

The environmental and climatic sensitivity of insects makes them particularly useful in studying the Arctic interface zones that people have struggled to survive in for millennia. These regions not only provide challenges for the human populations attempting to survive there, but also tend to be more susceptible to the impacts that these attempts bring upon them. Beyond the reaches of historical documentation, the impact of northern peoples is poorly understood, and there is great scope its the study through proxy indicators – which are the only alternative available for the reconstruction of the past, which cannot be measured directly.

Apart from potentially containing a proxy record of human impact at numerous sites throughout Europe, BugsCEP has the potential to help in the prediction of future human and natural impacts on the environment by way of predictive modelling. The BugsMCR ‘Predict’ module is a start, and the refinement of this system, in combination with fine-tuning and testing of the BugStats reconstruction component, could provide a base for modelling the potential changes in insect populations in the future. In the areas of forestry and agriculture, rewilding/naturalization projects, and the development of sustainable resource management there are great potentials for changes in the insect populations that could have far reaching consequences for both the biodiversity and industrial or agricultural sustainability of the regions concerned. BugsCEP’s database of Quaternary sites contains a wealth of palaeo-biodiversity information that would be of benefit in any attempt to model the present or future changes in beetle populations, especially under constrained change conditions.

7.2 Databasing the Humanities

Although it is a multi disciplinary database, and not a humanities database in the strict sense, BugsCEP can be used to provide support for integrated studies into the history of the interactions between people and the environment. This is a major theme in current research at the European level, and includes such diverse aspects as predicting the public effects of sustainable development policies to climate change studies. The humanities appear to be entering a paradigm where empirical data, and thus the large scale management of this, is essential for underpinning conclusions drawn on the human condition. This is especially important in the eyes of the public, and other scientific disciplines, such as the environmental sciences, where theories of the economic rationality of resource use alone cannot satisfactorily explain patterns of past impacts. As yet, the large scale databasing, and even

computerization, of the humanities is underdeveloped in Sweden (Vetenskapsrådet, 2005), with the notable exception of facilities such as the Demographic Data Base (Demografiska databasen[i]), a number of linguistic databases, and projects associated with the 'humanities IT environments' (e.g. HUMlab[ii]). There are a number of large palaeoenvironmental databases (see Chapter 1) which could be usefully integrated with archaeological, and related, data, were it available in a transferable form. The human aspect is frequently missing in palaeoenvironmental studies from the ecological and environmental sciences, often due to a lack of access to the data or the skills to interpret it. The complex nature of archaeological dating, and the wealth of data confined to so called grey literature (e.g. site reports, consultancy work), are perhaps two of the main reasons why raw archaeological site data are not currently available, on a large scale, at a suitable resolution for such integration. Database initiatives, such as SEAD (The Strategic Environmental Archaeology Database, Buckland *et al.,* 2006), and hopefully others sponsored by the EU's research infrastructure initiatives[iii], should help to bridge this gap and provide greater scope for inter-faculty cooperation. In addition, interdisciplinary cooperation, and the use of inherently non-disciplinary resources such as HUMlab could provide innovative solutions to data mining and visualization problems that would not normally be thought of within the confines of traditional disciplinary boundaries.

7.3 Future Directions and Final Thoughts

This thesis may ask more questions than it answers, as is often the case in doctoral research. Whilst BugsCEP provides the basis for improving the efficiency and power of palaeoenvironmental investigations, there are many aspect which could be developed further. The expansion of the scope of the database, to include more taxa, including Diptera, Formicidae and Trichoptera, which are amongst the groups more commonly found fossil, is a high priority. In addition, the start that was made on the parallel Bugs-like molluscan database, Slugs, which was begun with the late David Keen, should be built upon. The geographical expansion of the database, into southern and eastern Europe, but also other areas of the world would be of great benefit to the Quaternary research community, and work is already in progress to assemble a North American version. The Egyptian version, EgBugs (Buckland *et al., in press*), is proof of concept for the viability of this idea. There is also potential for the growth of the use of Coleoptera in climate change studies, with the improvement and refinement of the MCR dataset.

Besides these grand schemes, there are also a number of smaller enhancements that could improve the usefulness of BugsCEP, such as time-scaled graphing of outputs, additional variables and statistics, and possibly even the calculation of age-depth curves. The unfinished, experimental systems, such as the MCR jackknifing, and querying by fossil date routines, need to be completed, tested and released. Further testing of the Bugs EcoCode system, including comparison with other existing habitat classifications on both modern and fossil faunas is also necessary.

The development of a web based version of BugsCEP, including GIS and data submission facilities, would be an important step towards providing a system which can be integrated into a resource for the multi-proxy interrogation of Quaternary data. Whilst a prototype structure was created using MS SQL-Server (primarily to enable the construction of the database diagrams used in this thesis), the data transfer and web development aspects are yet to be undertaken, and are a high priority for future development. Similarly important is the inclusion of illustrations, which will undoubtedly increase the public appeal and teaching potential.

Although BugsCEP can be used for complex environmental and climatic reconstructions, it only uses insect data, and there is always a need for comparison with other proxy sources. Multi-proxy databases, such as LNED and SEAD (see Chapter 1) are essential if we are to improve on our ability to understand the past. Single proxy databases, such as BugsCEP, and others mentioned in Chapter 1,

[i] http://www.ddb.umu.se/
[ii] http://www.humlab.umu.se/humlabinenglish
[iii] http://cordis.europa.eu/esfri/

are vital building blocks in these developments. These databases, and their associated web portals and support networks should strive to reach potential users outside of the traditional educational establishments, and the immediately relevant disciplines of Quaternary geology and archaeology, where a diversity of backgrounds may bringing new approaches to the interpretation of the data.