Institution: University of Oxford

Unit of Assessment: 17A – Geography, Environmental Studies and Archaeology: Archaeology

Title of case study: Accurately dating the past – OxCal: free software for the calibration of radiocarbon dates

1. Summary of the impact

OxCal is the most popular software package world-wide for calibrating and analysing dates within the carbon dating process, enabling the accurate dating of objects from the past. The brainchild of Prof. Christopher Bronk Ramsey, Director of the Oxford Radiocarbon Accelerator Unit (ORAU), OxCal is based on chronologies refined by the use of Bayesian statistical methods, and provides users with access to high-quality calibration of chronological data, now the basis for global chronologies. It is available online and free to download, and has played a highly significant role in establishing the ORAU as one of the pre-eminent international radiocarbon dating facilities. Funded by the NERC, and used widely within professional archaeology as well as other disciplines, OxCal has also played a key role in research projects (within Oxford and beyond) brought to the attention of the general public by the media.

2. Underpinning research

OxCal was developed by Christopher Ramsey (Professor of Archaeological Science) at the ORAU, to help with the application of Bayesian statistical methods to the radiocarbon dating of archaeological material. Since then it has been applied across a range of dating techniques including Luminescence dating and Uranium series dating. By providing a method to build coherent and accurate chronologies from a whole range of types of scientific data, OxCal makes a significant contribution to both academia and society's understanding of the past.

Building on statistical research by Cliff Litton and Caitlin Buck at the Division of Statistics, Nottingham University, Ramsey developed OxCal as a software tool which could be easily distributed to users world-wide, and the first version of OxCal was presented in 1994 at the 15th International Radiocarbon Conference, Glasgow, and freely distributed by disc. Through the subsequent involvement of OxCal in other radiocarbon dating projects, Ramsey developed the software to allow greater flexibility in types of data that could be analysed, including more complex stratigraphical relationships **[Section 3: R1; R2].** In 2008, deposition models (environmental sequences relating to depth and age) were developed and incorporated into the calibrations **[R3]**. Finally, in 2013, funded as part of the NERC RESET consortium grant **[see section 3]**, a new version (version 4.2) incorporated new types of model suited to studying cultural developments by allowing for gradual rather than abrupt change, and the ability to display chronological data in a geographical context through mapping **[R4]**.

The use of OxCal has also been central to the partnership between Oxford University's Radiocarbon Acceleration Unit and that of the University of Glasgow, East Kilbride. Together, they are funded by the NERC and the AHRC as a national radiocarbon dating service which serves, on average, around100 academics and 30 doctoral students per year. Ongoing developments to OxCal have been widely disseminated by Ramsey through keynote lectures, conference papers and talks within the UK, Europe, the US, and Japan. Ramsey has presented more than 12 conference papers and public lectures between 2008 and 2013, to archaeological and other academic audiences (including the Geological Society). The research has also been disseminated through frequent publication in peer-reviewed journals such as *Radiocarbon*; these publications have a strong presence in the citation indices.

OxCal is employed in a wide range of research projects, and has a direct impact on the most fundamental of archaeological questions: date. For example, it was used and further developed as part of the international Egyptian Chronology Project (2006-2009), funded by the Leverhulme Trust **[R7]** and led by Ramsey, to test the correspondence between historical chronology and the radiocarbon dating of archaeological material. This research produced findings which suggest that the New Kingdom started between 1570 and 1544 B.C.E, earlier than previous historical estimates **[R5]**. These results were disseminated through publication, including the *Science* magazine, and in an open conference held in 2010, and received significant press attention. This work was the subject of a book published by OxBow in 2013 and has led to a follow-on Leverhulme-funded project looking at the origins of the Egyptian state.

The development of OxCal has also been supported by the work of two doctoral students at Oxford university, engaged in scientific dating projects. Daniel Miles (2001-2005; now an honorary research associate and Senior Partner at the Oxford Dendrochronology Laboratory) undertook, as part of his thesis, the development of the OxCal software for use in tree-ring dating; and Sharen Lee's NERC-funded DPhil (2008-2012), which included work on statistical methods for OxCal in her study of human responses to rapid environmental transitions, where she focussed on methods to assess rates of change in the archaeological record.

3. References to the research

Publications:

[R1] Bayliss, A., and Bronk Ramsey, C. 2004. Pragmatic Bayesians: a decade of integrating radiocarbon dates into chronological models. In C. E. Buck and A. R. Millard (eds), *Constructing Chronologies: Crossing Disciplinary Boundaries* (Lecture Notes in Statistics 177), 25-41.
[R2] Bronk Ramsey, C. 2009. Bayesian analysis of radiocarbon dates. *Radiocarbon* 51(1), 337-360.
[R3] Bronk Ramsey, C. 2008. Deposition models for chronological records. *Quaternary Science Reviews* 27(1-2), 42-60.
[R4] Lee, S. and Bronk Ramsey, C. 2012. Development and application of the trapezoidal models for archaeological chronologies. *Radiocarbon*, 54(1), 107-122.
[R5] News article on the results of the Egyptian Chronology Project, published in *Nature* in 2010 (doi: 10.1038/news.2010.304): http://www.nature.com/news/2010/100617/full/news.2010.304.html

Grants:

NERC Consortium grant of £588,000 the Research Laboratory for Archaeology and the History of Art (RLAHA) at Oxford's School of Archaeology at Oxford, as part of the overall project RESET ('Response of Humans to Abrupt Environmental Transitions'). 2008-2013. Within the RLAHA, C. Ramsey is the Co-Investigator coordinating Topic WP-7: the project's data synthesis and age modelling.
RESET project website: http://c14.arch.ox.ac.uk/reset/embed.php?File=index.html
RESET Topic WP-7 webpage: http://c14.arch.ox.ac.uk/reset/embed.php?File=WP7.html

Leverhulme Trust research grant (F/08 622/A) of £245k. 2006-2009. To support development of methods for the Egyptian Chronology Project. Principal Investigator: C. Ramsey.

OxCal website and programme:

OxCal website, with access to programme: http://c14.arch.ox.ac.uk/oxcal.html

4. The contribution, impact or benefit

Oxcal's reach is broad thanks to the fact that it is free to download, and to use online, and thus attracts a large number of users, including professional organisations, research bodies, and archaeological enthusiasts. In the last year (up to the end of the census period) there were 5,343 active external users of OxCal who used the programme more than once. The programme is accessed from outside the RLAHA about 35,000 times a year, or about once every 15 minutes. Of these external users almost half (2,416) are using the programme very regularly (on average just over once per month, accounting for 86% of the total external usage). At the time of writing there are 12,800 sites linking to OxCal with 4,600 direct links to the programme. Through the Oxford-East Kilbride Partnership, OxCal is also used as part of the dating services offered to both the academic community and non-academic users. It also features in the curricula of a number of UK and overseas HEI scientific archaeology courses, which has significantly contributed to the training of both academic and non-academic users in the use of this software and dating techniques, and features on a number of HEI courses beyond the UK, for example Harvard's Anthropology course **[Section 5: C7]**.

OxCal's impact on archaeological dating beyond academia is particularly significant for two major groups of users:

1. Professional organisations:

Of the wide array of professional users, three examples are given here to show the breadth and

depth of the impact of OxCal on the commercial sector, both in the UK and abroad.

a) **English Heritage** (EH) uses OxCal for calibrating all dates produced in their date lists **[C1, C2]**; they recommend the use of OxCal to commercial archaeological units; and have funded numerous projects in which OxCal has been used. One such recent project, 'Gathering Time', published in 2011, was a major radiocarbon dating programme jointly funded by EH and the AHRC, comprising the largest application of the Bayesian approach to modelling archaeological chronologies ever undertaken. The use of the Bayesian chronological model to interpret the radiocarbon dates was pivotal to the success of the project, providing more precise timescales for monument construction than had previously been possible **[C3]**. All the chronological modelling was undertaken using the programme OxCal version 3.10; as noted in the publication, 'Without this type of user-friendly software and modular model construction, an application on this scale would simply not have been possible' **[C3,** reference 3, p.58**]**. The results revised our picture of Early Neolithic Britain and Ireland, establishing that the main period of construction of causewayed enclosures was much briefer than previously assumed, and revealing concentrated episodes of construction. In 2006, the format of OxCal was changed so that it could be accessed online and thus be compatible with all computer systems (version 4.0); these developments were funded by a grant of £20k from English Heritage as part of their Historic Environment Enabling programme.

b) The **United States Geological Survey**, a scientific agency of the US government, uses OxCal as a tool for constructing chronologies **[C4; C5]**. Specifically, OxCal is used to analyse recurrence rates of environmental hazards such as earthquakes from the geological record, which provide a critical constraint in estimating the seismic hazards posed by active faults. These data are then used to calculate the risks of further events **[C5]**. This is made possible by the model's incorporation of all chronological constraints (including stratigraphic order, the timing of the most recent event, and historical constraints), which is freely available to paleoseismologists as part of the current OxCal version.

c) The **Oxford Dendrochronology Laboratory** (ODL) is a commercial tree-ring laboratory set up by Ramsey's former doctoral student and OxCal specialist, Dr Daniel Miles. Using OxCal as part of their methods, Miles and his colleague Martin Bridge (as the Senior Partners) provide dating services for private projects, as well as for EH, the Historic Royal Palaces Agency and various professional archaeology units. Between 2008 and 2013, 20 timber buildings (including churches, domestic structures and one hospital) across England have had the felling date ranges made much more precise through the application of the OxCal tool, in some instances having a significant effect on the interpretation of the buildings being studied. The Brethren's Hall at St Cross Hospital, Winchester, for example, had its felling date range reduced from 28 years to 14, allowing the builder to be identified as Cardinal Henry Beaufort **[C6]**.

2. The general public:

By making OxCal free, Ramsey has made the software available to all those who wish to use it. Individuals with a particular interest are supported by a dedicated OxCal e-mail list, and by an online discussion group used by academics and non-academics across the globe **[C8].**

OxCal has also had an impact on the wider public by underpinning various research projects of significant public interest which have received broad media coverage. Three examples are given here, in which the extra precision that OxCal has made possible has led to significant improvements in dating, sufficient to have captured the public's imagination:

a) The bones excavated under **Greyfriars Church** in Leicester, in 2012, and subsequently identified as belonging to Richard III have attracted a great deal of public interest; the radiocarbon dating of the bones, which used the OxCal programme, was critical to this analysis and identification, as reported in the BBC news and a Channel 4 documentary **[C9]**.

b) The radiocarbon dating of **David Attenborough's Madagascan 'elephant bird' egg**, carried out by the Oxford Radiocarbon Accelerator Unit, also used the OxCal tool; the result was broadcast in a BBC documentary in 2011 **[C10]**, where the egg was shown to belong towards the

end of a series of dates for this avian species previously gathered by the ORAU, and it was shown that the bird had co-existed with human occupants of Madagascar for some time before its extinction by the end of the 1st millennium AD.

c) The findings of the **Egyptian Chronology Project**, discussed above, also received significant press attention within the UK in 2010, in national press (e.g. the BBC and Daily Mail), on popular archaeology sites (e.g. AboutArchaeology.com), and in popular science publications (e.g. *Nature* and *Science*) **[C11]**.

5. Sources to corroborate the impact

Professional organisations:

[C1] Letter of support from the Head of Strategic Planning and Management Division, English Heritage, confirming the importance of the OxCal calibration software for the archaeological profession in England.

[C2] Bayliss, A., Bronk Ramsey, C., Cook, G., van der Plicht, J. and McCormac, G. 2008. *Radiocarbon Dates: From Samples funded by English Heritage under the Aggregates Levy Sustainability Fund 2004-7*. Available at http://www.english-heritage.org.uk/publications/radiocarbon-dates-alsf-2004-7/

[C3] Whittle, A., Healy, F. and Bayliss, A. (eds) 2011. *Gathering Time: Dating the Early Neolithic Enclosures of Southern Britain and Ireland*. Oxford: Oxbow Books.

[C4] Sample tutorial file for calculating ages of paleoearthquakes using Oxcal software, provided on the US Geological Survey's website: http://earthquake.usgs.gov/research/geology/paleoseis/oxcal/

[C5] Lienkaemper, J. J. and Bronk Ramsey, C. 2009. OxCal: Versatile tool for developing paleoearthquake chronologies - A primer. *Seismological Research Letters* 80(3), 431–434.

[C6] The Senior Partner at the Oxford Dendrochronology Laboratory (www.Oxford-DendroLab.com)

[C7] Syllabus of Harvard University's Anthropology course 2250A (2011), as one example of OxCal's impact on students and teaching which extends significantly beyond Oxford University: http://www.fas.harvard.edu/~anthro/flad/PDF/Anthro%202250a_Spring%202011.doc

Individual users and the general public:

[C8] OxCal Users Discussion Group online, demonstrating the range of non-academic and international users of OxCal: https://groups.google.com/group/oxcal/topics?hl=en

[C9] Dating of bones of Richard III ('Richard III: The King in the Car Park', Channel 4 documentary, Feb 2013): http://www.channel4.com/programmes/richard-iii-the-king-in-the-car-park/4od#3479296

[C10] David Attenborough documentary on the 'elephant bird' egg ('Attenborough and the Giant Egg', BBC documentary, March 2011): http://www.bbc.co.uk/programmes/b00z6dsg; https://cinaplay.com/Registration?&theme=tiger&a_aid=502d575be4629&a_bid=e4886c0f&chan=&pubid=&sid=&clickid=&subid=&g=d87590467c6b570c060563e334308f40&

[C11] Egyptian Chronology Project: reports by BBC, AboutArchaeology.com, The Daily Mail, Nature and Science: Links available at http://c14.arch.ox.ac.uk/embed.php?File=news.html