Calibrating Marine Radiocarbon Dates: A Guide to Australian ΔR Values

Introduction

Every year hundreds of radiocarbon dates are obtained on Australian marine shells and corals by archaeologists and geomorphologists. As a first approximation it is common practice to correct these dates for marine reservoir effect by simply subtracting a generalised factor of 450 ± 35 years to make them comparable to coeval terrestrial (e.g. charcoal) samples.

Gillespie calculated this correction value in the 1970s (see Gillespie 1975; Gillespie and Polach 1979; Gillespie and Temple 1977). Since that time several studies have suggested the possibility of significant deviations in regional marine reservoir signature from this generalised value (e.g. Hughes & Djohadze 1980; Murray-Wallace 1996; Spennemann & Head 1996; Ulm *et al.* 1999; Woodroffe & Mulrennan 1993; Woodroffe *et al.* 1986:75, 77).

In the time that has elapsed since Gillespie's pioneering study, researchers have gained a much more sophisticated appreciation of the complexity of global marine carbon reservoirs. One of the most significant developments was the calculation of a global model of marine ^{14}C activity that enabled the calibration of radiocarbon dates obtained on marine samples, including the ability to account for regional differences from the global model with the input of a local/regional ΔR value (Stuiver *et al.* 1986). Reimer and Reimer (2000, 2001) recently summarised all of the available global ΔR values in a world wide web database.

In this paper, I briefly discuss the principles of marine reservoir correction before presenting a guide to regional and subregional Australian ΔR values extracted from the Reimer and Reimer (2000, 2001) database and recent work presented in Ulm (2002).

Background

A basic assumption of the radiocarbon dating method is that the concentration of radioactive carbon (^{14}C) in the biosphere is uniform through space and time. Early in the development of the radiocarbon dating method, however, it was recognised that marine shells exhibited a systematic age difference to contemporary terrestrial samples on a regional basis that allowed calculation of a regionally specific age offset.

Global variation in marine reservoir effects evident in marine shell carbonates are principally caused by incomplete mixing of upwelling water of 'old' inorganic carbonates from the deep ocean where long residence times (>1000 years) cause depletion of ^{14}C activity through radioactive decay, resulting in very old apparent ^{14}C ages (Mangerud 1972). Estuarine reservoirs are even more complex with the interaction and incomplete mixing of ^{14}C from both terrestrial reservoirs and marine reservoirs from tidal action (e.g. Little 1993).

Regional differences in marine reservoir effect are generally determined through one or a combination of three methods:

1. direct radiocarbon dating pre-AD 1955 live-collected shell specimens of known historical age;

2. radiocarbon dating shell/charcoal paired samples from high integrity archaeological contexts that are assumed to be contemporaneous;

3. radiocarbon dating and/or paired radiocarbon and uranium-thorium ($^{230}Th/^{234}U$) dating of live corals or long-lived live shells with clear annual growth bands.

In the first method, marine shell specimens of known historical age must be live-collected prior to AD 1955 and the date and location of live-collection known with confidence. After AD 1955 natural levels of ^{14}C activity in marine environments were enriched as a result of detonation of nuclear and thermonuclear weapons in the atmosphere. Dating shell/charcoal paired samples is potentially problematic because it must be assumed that the samples selected are contemporaneous and that association is not simply the result of post-depositional processes, excavation procedures or erroneous interpretation. Therefore such data need to be considered carefully on an individual basis. Owing to these problems ∆R values calculated from shell/charcoal pairs are not included in this guide (or in the Reimer and Reimer database). Recent studies have demonstrated that radiometric dating of certain coral species with well-defined annual growth structures can provide the most accurate determination of local marine reservoir effects (Reimer and Reimer 2000). Unfortunately, few such coral studies are available and they are limited largely to tropical regions with long-term coral records.

In recent years, regional marine reservoir effect has commonly been expressed as a ∆R value (e.g. Higham & Hogg 1995; Phelan 1999). Stuiver *et al.* (1986; Stuiver & Braziunas 1993; Stuiver *et al.* 1998) modelled global marine ^{14}C activity using a simple box diffusion global carbon cycle model of marine reservoir responses to variation in atmospheric ^{14}C activity. Regional deviations from the modelled marine calibration curve (∆R) were calculated using radiocarbon ages on live-collected marine shell samples of known historical age (Stuiver *et al.* 1986: Table 1). ∆R is the difference between the conventional radiocarbon age of a sample of known age from a specific locality (P) and the equivalent age predicted by the global modelled marine calibration curve (Q); therefore $\Delta R = P - Q$ (Stuiver *et al.* 1986: 982).

Once calculated, the ∆R value can be applied to marine calibration curves to calibrate dates obtained on marine shell (and other marine-derived sample materials such as fish bone, marine mammal bone etc.) for specific regions. The ∆R value can also be used in widely available computer calibration programs such as CALIB (Stuiver and Reimer 1993) and OxCAL (Bronk Ramsey 1995).

Australian ∆R Values: A Guide

Reimer and Reimer (2000, 2001) recently launched a world wide web database of ∆R values (available at http://calib.org/marine). In the *Marine Reservoir Correction Database* Reimer and Reimer (2000, 2001) recalculated world-wide ∆R values using the latest calibration dataset of Stuiver *et al.* (1998). For Australia, Reimer and Reimer (2000) present pooled regional ∆R values for Northeast, North and Northwestern, Southern and Southeastern Australia

(Figure 1, Table 1). These regional values combine between two and 11 individual ∆R values and cover very broad geographical regions composed of potentially different marine reservoir conditions. Therefore, in addition to the regional ∆R values I have calculated subregional ∆R values where two or more individual ∆R values are available for a specific area (Table 2). Like the regional values, the subregional ∆R value is the error-weighted mean of the values available. Error-weighted means were calculated using the procedures and methods outlined by Ward and Wilson (1978), with all sample groups presented forming statistically indistinguishable groups.

Figure 1. Map of Australia, showing regional and subregional ∆R values. ∆R values in bold denote regional values. Those without bold are subregional values.

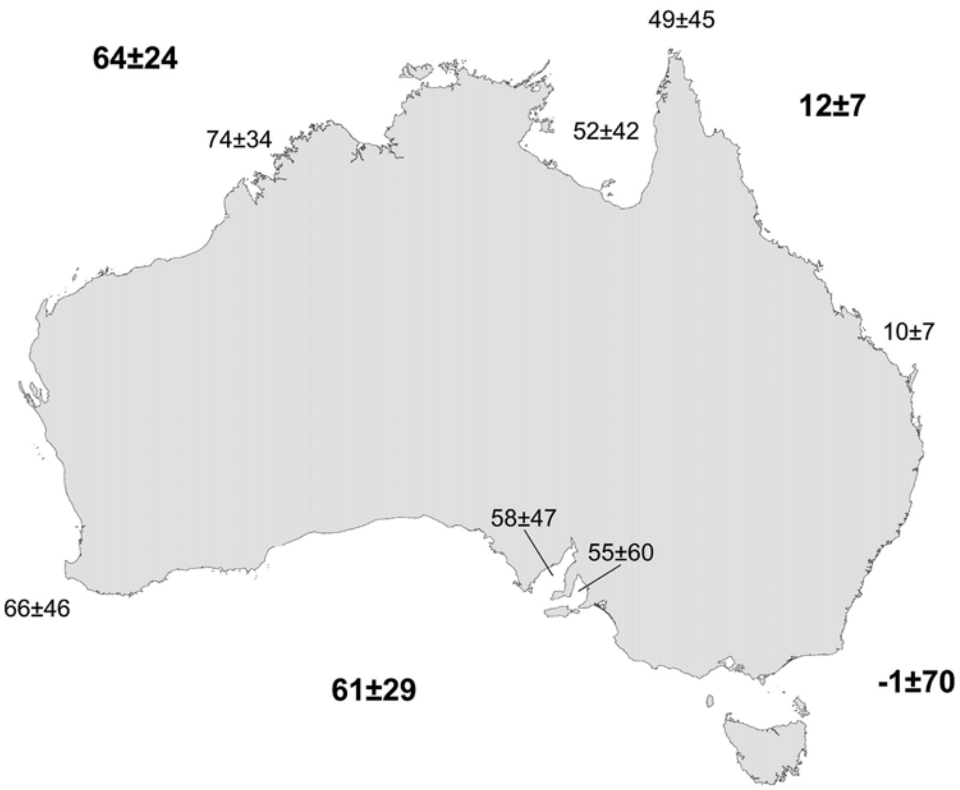

Table 1. Regional average ∆R values (after Reimer and Reimer 2000; Ulm 2002).

Region	# ∆R Values	Regional Average
Northeast Australia	12	12±7
North & Northwestern Australia	9	64±24
Southern Australia	11	61±29
Southeastern Australia	2	-1±70

Table 2. Subregional average ∆R values (after Reimer and Reimer 2000; Ulm 2002).

Subregion	# ΔR Values	Subregional Average
Torres Strait	3	49±45
Gulf of Carpentaria	2	52±42
Kimberley Region	7	74±34
Southwest Western Australia	4	66±46
Spencer Gulf	5	58±47
Gulf of St Vincent	2	55±60
Central Queensland	7	10±7

Discussion

The choice of a particular ΔR value to calibrate a particular radiocarbon date must be based on a consideration of the environment in which the sample material was formed. For example, in a study of ΔR values for a number of estuaries in central Queensland I recently calculated estuary-specific values of up to ΔR= -155 ± 55 (see Ulm 2002 for detailed discussion). In this case, the blanket application of the regional or subregional ΔR value would have produced calibrated ages approximately 200 years too young.

In the absence of additional information, it is assumed that temporal changes in ΔR for a specific region coincide with changes in the global model ocean (Stuiver *et al*. 1998: 1135). Time-factored ΔR(t) (t=time) values can be calculated through large-scale studies of annual coral records and/or paired shell/charcoal samples from a variety of time periods (e.g. Kennett *et al*. 1997; Ingram 1998).

A quick perusal of Figure 1 will highlight major gaps in the availability of ΔR values for the Australian coast. These gaps pose significant issues for regions such as coastal New South Wales where numerous coastal shell midden deposits have been excavated and dated on the basis of marine shell samples with no local ΔR values available.

References

Bronk Ramsey, C. 1995. Radiocarbon calibration and analysis of stratigraphy: The OxCal program. *Radiocarbon* 37(2): 425–430.

Gillespie, R. 1975. The suitability of marine shells for radiocarbon dating. Unpublished PhD thesis, University of Sydney, Sydney.

Gillespie, R. and H.A. Polach, 1979. The suitability of marine shells for radiocarbon dating of Australian prehistory. In R. Berger and H. Suess (eds), *Proceedings of the Ninth International Conference on Radiocarbon Dating*, pp. 404–421. Los Angeles: University of California Press.

Gillespie, R. and R.B. Temple, 1977. Radiocarbon dating of shell middens. *Archaeology and Physical Anthropology in Oceania* 12: 26–37.

Higham, T.F.G. and A.G. Hogg, 1995. Radiocarbon dating of prehistoric shell from New Zealand and calculation of the ΔR value using fish otoliths. *Radiocarbon* 37: 409–416.

Hughes, P.J. and V. Djohadze, 1980. *Radiocarbon Dates from Archaeological Sites on the South Coast of New South Wales and the Use of Depth/Age Curves*. Occasional Papers in Prehistory 1. Canberra: Department of Prehistory, Australian National University.

Ingram, B.L. 1998. Differences in radiocarbon age between shell and charcoal from a Holocene shellmound in northern California. *Quaternary Research* 49: 102–110.

Kennett, D.J., B.L. Ingram, J.M. Erlandson and P.L. Walker, 1997. Evidence for temporal fluctuations in marine radiocarbon reservoir ages in the Santa Barbara Channel, southern California. *Journal of Archaeological Science* 24: 1051–1059.

Little, E.A. 1993. Radiocarbon age calibration at archaeological sites of coastal Massachusetts and vicinity. *Journal of Archaeological Science* 20: 457–471.

Mangerud, J. 1972. Radiocarbon dating of marine shells, including a discussion of apparent ages of Recent shells from Norway. *Boreas* 1: 143–172.

Murray-Wallace, C.V. 1996. Understanding 'deep' time - Advances since Archbishop Ussher? *Archaeology in Oceania* 31: 173–177.

Phelan, M.B. 1999. A ΔR correction value for Samoa from known-age marine shells. *Radiocarbon* 41: 99–101.

Reimer, P. and R. Reimer, 2000. Marine reservoir correction database. http://calib.org/marine

Reimer, P.J. and R.W. Reimer, 2001. A marine reservoir correction database and on-line interface. *Radiocarbon* 43(2A): 461–463.

Spennemann, D.H.R. and M.J. Head, 1996. Reservoir modification of radiocarbon signatures in coastal and near-shore waters of eastern Australia: The state of play. *Quaternary Australasia* 14: 32–39.

Stuiver, M. and T.F. Braziunas, 1993. Modeling atmospheric ^{14}C influences and ^{14}C ages of marine samples to 10,000 BC. *Radiocarbon* 35: 137–189.

Stuiver, M., G.W. Pearson and T. Braziunas, 1986. Radiocarbon age calibration of marine samples back to 9000 cal yr BP. *Radiocarbon* 28: 980–1021.

Stuiver, M. and P.J. Reimer, 1993. Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. *Radiocarbon* 35: 215–230.

Stuiver, M., P.J. Reimer and T.F. Braziunas, 1998. High-precision radiocarbon age calibration for terrestrial and marine samples. *Radiocarbon* 40: 1127–1151.

Ulm, S. 2002. Marine and estuarine reservoir effects in central Queensland, Australia: Determination of ΔR values. *Geoarchaeology* 17(4): 319–348.

Ulm, S., M. Carter, J. Reid and I. Lilley, 1999. Eurimbula Site 1, Curtis Coast: Site report. *Queensland Archaeological Research* 11: 105–122.

Ward, G.K. and S.R. Wilson, 1978. Procedures for comparing and combining radiocarbon age determinations: A critique. *Archaeometry* 20: 19–31.

Woodroffe, C.D. and M.E. Mulrennan, 1993. *Geomorphology of the Lower Mary River Plains Northern Territory*. Darwin: Northern Australian Research Unit, Australian National University and Conservation Commission of the Northern Territory.

Woodroffe, C.D., J.M.A. Chappell, B.G. Thom and E. Wallensky, 1986. *Geomorphological Dynamics and Evolution of the South Alligator Tidal River and Plains, Northern Territory*. Mangrove Monograph 3. Darwin: North Australian Research Unit, Australian National University.

Sean Ulm

Aboriginal and Torres Strait Islander Studies Unit, University of Queensland, Brisbane, Queensland