PRE-BOMB MARINE RESERVOIR VARIABILITY IN THE KIMBERLEY REGION, WESTERN AUSTRALIA

Sue O'Connor[1,2] • Sean Ulm[3] • Stewart J Fallon[4] • Anthony Barham[1] • Ian Loch[5]

ABSTRACT. New ΔR values are presented for 10 known-age shells from the Kimberley region of northwest Australia. Previous estimates of ΔR for the Kimberley region are based on only 6 individual shell specimens with dates of live collection known only to within 50 yr (Bowman 1985a). Here, we describe the results of our recent attempts to constrain ΔR variability for this region by dating a suite of known-age pre-AD 1950 shell samples from the Australian Museum and Museum Victoria. A regional ΔR of 58 ± 17 ^{14}C yr for open waters between Broome and Cape Leveque is recommended based on 7 of these specimens. The criteria used to select shells for dating and inclusion in the regional mean are discussed.

INTRODUCTION

Marine shell is the dominant organic component of shell middens and is routinely dated by archaeologists working in coastal regions of Australia and the Pacific in order to establish regional chronologies for indigenous occupation. Although the archaeological community is now cognizant of the fact that radiocarbon dates obtained on terrestrial and marine samples are not directly comparable, and that an oceanic reservoir correction needs to be applied to dates on marine materials in order to render then comparable with terrestrial ages, the degree of variation in ^{14}C activity at the local and regional level for marine environments for much of the Australian coastline is still poorly or entirely unknown (Ulm 2006). While regional correction values can be calculated using the Marine Reservoir Correction Database (Reimer and Reimer 2009) for some regions, where there have been no regionally specific studies into marine variability, the use of a generic ΔR correction to calibrate marine and estuarine shell dates entails a level of uncertainty (Ulm et al. 2009).

For the Kimberley region, there has been 1 previous study of ΔR (Figure 1). Bowman (1985a) dated 5 specimens from the Broome region collected by Bernard Bardwell before 1950. Unfortunately, the date of collection for these samples was only able to be constrained using biographical data to the period between AD 1902 and 1950, leading to a large error term in the results. Bowman also dated a single specimen from Port George, 380 km north of Broome (Table 1).

Aside from the fact that the dates of collection of the samples were poorly constrained, there are several other potential problems posed by the samples selected for dating. Bowman (1985a) dated a variety of species including an herbivorous gastropod (CS-444) and a deposit-feeding bivalve (CS-443) rather than suspension-feeding bivalves, which are now known to provide the most reliable sample material for ΔR studies (Forman and Polyak 1997; Hogg et al. 1998). In addition, CS-441 actually consists of 3 individual small specimens with potentially different life histories. Singly and in combination these factors may significantly impact on the robustness of any ΔR values calculated using these results.

As few known-age shell samples have been dated for the Australian coast (Gillespie 1977; Rhodes et al. 1980; Bowman and Harvey 1983; Bowman 1985a,b) archaeologists often rely on dating paired

[1]Department of Archaeology and Natural History, Research School of Pacific and Asian Studies, Australian National University, Canberra, ACT 2601, Australia.
[2]Corresponding author. Email: sue.oconnor@anu.edu.au.
[3]Aboriginal and Torres Strait Islander Studies Unit, The University of Queensland, Brisbane, QLD 4072, Australia.
[4]Research School of Earth Sciences, Australian National University, Canberra, ACT 2601, Australia.
[5]Australian Museum, 6 College Street, Sydney, NSW 2010, Australia

Proceedings of the 20th International Radiocarbon Conference, edited by A J T Jull
RADIOCARBON, Vol 52, Nr 2–3, 2010, p 1158–1165

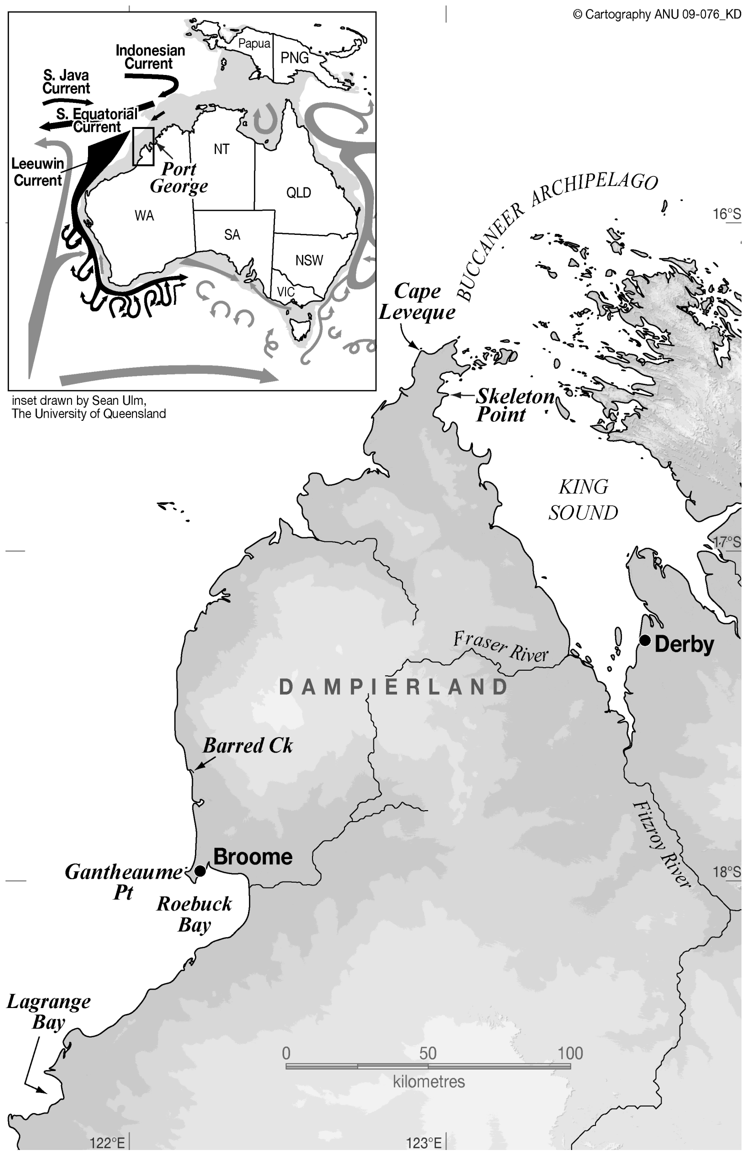

Figure 1 The Kimberley region, showing locations mentioned in the text. Inset shows location of the study area and major surface ocean currents (after CSIRO 2000).

marine/terrestrial samples in order to calculate regional ΔR (e.g. Gillespie and Temple 1977; Head et al. 1983; Ascough et al. 2009; Bourke and Hua 2009). However, there are a number of inherent assumptions in this method that are untestable, and which may result in unreliable estimates, including the assumption of contemporaneity for the shell and charcoal. In reality, the shell and charcoal in middens, although spatially associated at the point of collection, may have been deposited over many decades or even hundreds of years, or may have been reworked as a result of a variety of natural or cultural causes. Additionally, while the assumption that the shell was live-collected immediately prior to deposition may be reasonable, the wood producing the charcoal may have an inbuilt age. Ulm et al. (2009) discount the "old wood problem," deriving from the use of inner wood from

Table 1 Previous ΔR values for northeast Australia (see Bowman 1985a). Note dates CS-439 and CS-440 are from opposing valves of a single individual specimen. The 2 dates are indistinguishable and are combined here. See Figure 1 for locations.

Location	Family	Species[a]	Diet[b]	Collection year	Marine model age [Rs(t)]	CRA[c] [Rg(t)]	ΔR [Rs(t)–Rg(t)]	Lab nr (CS-)
Broome	Veneridae	*Periglypta resticulata*	SF	1926 ± 24	454.8 ± 23	561 ± 78	106 ± 78	439
Broome	Veneridae	*Periglypta resticulata*	SF	1926 ± 24	454.8 ± 23	467 ± 78	12 ± 78	440
Error-weighted mean		$T' = 0.73$; $\chi^2_{1:0.05} = 3.84$					59 ± 66	
Broome	Cypraeidae	*Erosaria caputserpentis caputserpentis*[1]	O	1926 ± 24	454.8 ± 23	463 ± 109	8 ± 109	441
Broome	Tellinidae	*Tellinella virgata*[2]	SF/DF	1926 ± 24	454.8 ± 23	459 ± 119	4 ± 119	443
Broome	Turbinidae	*Turbo (Marmarostoma) squamosus*[3]	H	1926 ± 24	454.8 ± 23	410 ± 119	–45 ± 119	444
Broome	Cypraeidae	*Cypraea tigris*	O	1926 ± 24	454.8 ± 23	564 ± 78	109 ± 78	445
Port George[d]	Crassatellidae	*Eucrassatella cumingii*[4]	SF	1926 ± 24	454.8 ± 23	646 ± 78	191 ± 78	442
Error-weighted mean of Broome samples		$T' = 1.52$; $\chi^2_{4:0.05} = 9.49$					47 ± 59	

[a]Nomenclature has been updated using the Indo-Pacific Molluscan Database. 1 = syn. *Cypraea caputserpentis*; 2 = syn. *Tellina virgata*; 3 = syn. *Turbo laminiferus*; 4 = syn. *Eucrassatella cumingi*.
[b]H = herbivore; SF = suspension feeder; DF = deposit feeder; O = omnivore.
[c]CRA = conventional radiocarbon age.
[d]Excluded from error-weighted mean.

old trees that has been dead for many years prior to burning, as significant in tropical environments, as they argue that it is unlikely that wood will survive for more than a few decades in seasonally wet/dry climates where termites are active. Regardless of whether or not this is the case, the age of the wood adds an unknown error to the dates obtained.

Reliable regional ΔR estimates are best achieved by dating shells, coral, or other marine organisms of known age. As Petchey (2009) and Ulm (2006) emphasize, it is essential that the shell specimens selected for dating meet strict criteria:

- **They must have been collected as live specimens.** Many specimens examined in the Australian Museum and Museum Victoria dry collections had lost color or had slight edge rounding indicating that they may have been exposed on the surface for some time after death before collection (e.g. archaeological deposit, natural beach ridge) or collected as beach-washed specimens. Only specimens with definite evidence of live collection, such as appropriate documentation, the retention of the dessicated animal or the presence of residual ligamental tissue were accepted for this study.
- **They must have collection dates pre-dating atmospheric nuclear weapon testing, which resulted in enriched atmosphere and ocean ^{14}C levels (AD 1950).** The "bomb effect" has been detected in north and south Pacific coral cores and Indonesian Throughflow coral cores from as early as 1956 (Konishi et al. 1982; Druffel and Griffin 1999; Fallon and Guilderson 2008). Petchey (2009) also notes that ideally historic specimens should pre-date AD 1850 as post-AD 1850 coral and shell records have been shown to record anthropogenic effects such as dilution in ^{14}C caused by burning fossil fuels.
- **They should have specified collection dates that confine their collection to a single year.** Many of the amateur shell collectors who donated to museums collected over periods of decades, and often collections were acquired by the museums many years subsequent to their collection (e.g. after the death of the collector). In some cases, the date of specimen collection

can only be bracketed by the active years of a particular collector. Only specimens with a firm collection date or where collection can be constrained within a few years should be used.

- **They will have good provenance data (i.e. geographic location and local habitat).** Some species have wide habitat tolerances. There are many complexities that affect samples at the local level such as upwelling, tidal flushing, terrestrial runoff effects from freshwater input, and local geology (Stuiver and Braziunas 1993; Dye 1994; Ulm 2002; Ulm et al. 2009) As some species have wide tolerance levels, the exact collection provenance is essential. Estuarine species have also been shown to produce estuary-specific values that differ significantly from values from species obtained from proximal open coastal marine environments (Ulm 2002).
- **They will ideally be suspension-feeding species.** ΔR values will vary as a result of a species feeding habits (i.e. deposit feeders, algal grazers, or suspension feeders). Deposit feeders and algal grazers are likely to have a greater uptake of carbon from the sediments and geology they feed upon (Hogg et al. 1998). Some grazers with magnetite toughened teeth remove and ingest the surface of the rock with the algae, potentially exacerbating this problem.

METHODS

In an effort to improve the error term and provide a ΔR for the Kimberley region that could be reliably used for correcting archaeological shell dates, the collections of the Australian Museum and Museum Victoria were examined for suitable specimens. Over 100 shell specimens were examined of which only 10 were found from the Kimberley region that could be confidently assigned as live-collected. These specimens were ranked 1–3 depending on how narrowly the date of collection could be bracketed and the suitability of their habitat and diet for ΔR determination. Only those that had residual tissue still attached, a firm collection date, location and habitat provenance, and which were suspension feeders were ranked 1. Those with a firm collection date and provenance but which were not suspension feeders or were from estuarine habitats were ranked 2. These were dated for comparative purposes to establish variability in regional ΔR for the study area. Ulm's (2002) findings for central Queensland are pertinent here. He established an open-ocean ΔR of 11 ± 10 ^{14}C yr, but values for adjacent estuaries were found to diverge significantly and produced older values. Specimens ranked 3 did not sufficiently meet the criteria and were not dated. Specimens dated and the information on their provenance, habitat, and diet are presented in Table 2.

Following the recommendations of Culleton et al. (2006), a 8–10-mm-long and ~2-mm-wide sample was taken parallel to the shell margin avoid seasonal variation and give an average value over no more than 5 growth rings (Petchey et al. 2008). The sample material was then crushed to obtain small fragments. These fragments were subjected to acid leaching with 0.1M HCl. This resulted in a loss of ~20% of the outer surface material. Subsamples weighing ~10 mg were acidified with 0.5 mL of 85% orthophosphoric acid at 90 °C in an evacuated container. The evolved CO_2 was converted to graphite using a Fe catalyst and H_2 gas (water being removed during reaction with $Mg(ClO_4)_2$). Samples were analyzed on the single-stage accelerator mass spectrometer at the Research School of Earth Sciences at the Australian National University.

To calculate ΔR, the historical age of each shell sample (i.e. year of death) was converted to an equivalent global marine modeled age using the Marine04 calibration data set (Hughen et al. 2004). ΔR values were calculated by deducting the equivalent global marine model age at the time of death of the shell sample (Rg(t)) from the conventional ^{14}C age obtained (Rs(t)), therefore ΔR(s) = Rs(t) – Rg(t), where *s* is a specific location (Stuiver et al. 1986). ΔRσ is taken as the error in the ^{14}C age (after Reimer and Reimer 2009). The χ^2 test was used to evaluate the internal variability in a group of ΔR values (Ward and Wilson 1978). In pooling ΔR values, the error is the larger of the standard deviation in the mean and the weighted mean measurement error (Reimer and Reimer 2009).

Table 2 Details of dated live-collected shell specimens and ΔR results. * = excluded from regional mean calculation.

Rank	Museum ID	Species	Collector	Collection date	Location	Diet	Lab nr (SANU-)	CRA[a] [Rg(t)]	$\delta^{13}C$ (‰)	Marine modeled age [Rs(t)]	ΔR [Rs(t)–Rg(t)]
1	C119789 MAL# 35447	Pectinidae: *Mimachlamys scabricostata* (Sowerby, 1915)	A.A. Livingstone	Aug 1929	Broome [−17.962°S, 122.236°E]	SF	7720	520 ± 30	−6 ± 2	453.4 ± 23	67 ± 30
1	C57193 MAL# 9783B	Arcidae: *Barbatia (Barbatia) parvivillosa* (Iredale, 1939)	A.A. Livingstone	Aug 1929	Roebuck Bay [−18.086°S, 122.283°E]	SF	7730	520 ± 35	−7 ± 3	453.4 ± 23	67 ± 35
1	C412642 MAL# 42875	Pteriidae: *Pinctada albina* (Lamarck, 1819)	A.A. Livingstone	19 Aug 1929	Cape Leveque, NE side [−16.389°S, 122.925°E]	SF	7725	535 ± 30	−6 ± 2	453.4 ± 23	82 ± 30
1	C57195 MAL# 62790	Arcidae: *Barbatia amygdalumtostum* (Roding, 1798)	A.A. Livingstone	4 Sept 1929	Gantheaume Point [−17.973°S, 122.176°E]	SF	7731	515 ± 30	−5 ± 2	453.4 ± 23	62 ± 30
1	C426252 MAL# 42875	Veneridae: *Placamen tiara* (Dillwyn, 1817)	A.A. Livingstone	19 Aug 1929	Cape Leveque, NE side [−16.389°S, 122.925°E]	SF	7727	495 ± 30	−4 ± 2	453.4 ± 23	42 ± 30
1	C375612 MAL# 35447	Pectinidae: *Mimachlamys punctata* (Gmelin, 1791)	A.A. Livingstone	Aug 1929	Broome [−17.962°S, 122.236°E]	SF	7723	485 ± 35	−7 ± 3	453.4 ± 23	32 ± 35
1	Museum Victoria F74046	Placunidae: *Placuna ephippium* (Philippsson, 1788)	Bernard Bardwell	1922	Skeleton Point, King Sound [−16.522°S, 123.006°E]	SF	7732	500 ± 30	−8 ± 2	449.8 ± 23	50 ± 30
2*	C42221 MAL# 9143	Chitonidae: *Acanthopleura spinosa* (Bruguiere, 1792)	Dr H. Basedow	1916	Buccaneer Archipelago [−16.098°S, 123.431°E]	AG	7726	540 ± 30	−9 ± 2	448.2 ± 23	92 ± 30
2*	C50623 MAL# 69841	Veneridae: *Dosinia scalaris* (Menke, 1843)	E.H. Bardwell	~1924	Lagrange Bay [−18.652°S, 121.702°E]	SF	7729	570 ± 35	−8 ± 3	450.6 ± 23	119 ± 35
2*	Museum Victoria F28554	Tellinidae: *Tellina tenuilamellata* (E.A. Smith, 1885)	J.H. Gatliff Collection	16 Aug 1933	Barred Creek [−17.662°S, 122.194°E]	SF/DF	7907	870 ± 35	−4 ± 2	455.8 ± 23	414 ± 35
Error-weighted mean of specimens ranked #1			$T' = 1.71$; $\chi^2_{6:0.05} = 12.59$								58 ± 17

[a]CRA = conventional radiocarbon age.

RESULTS AND DISCUSSION

The regional weighted mean of $\Delta R = 58 \pm 17$ ^{14}C yr ($T' = 1.71$; $\chi^2_{6:0.05} = 12.59$) calculated using all the specimens ranked 1 in this study (Table 2) supports the results achieved by Bowman's (1985a) earlier study of $\Delta R = 47 \pm 59$ ^{14}C yr ($T' = 1.52$; $\chi^2_{4:0.05} = 9.49$) but reduces the error term substantially (Figure 2).

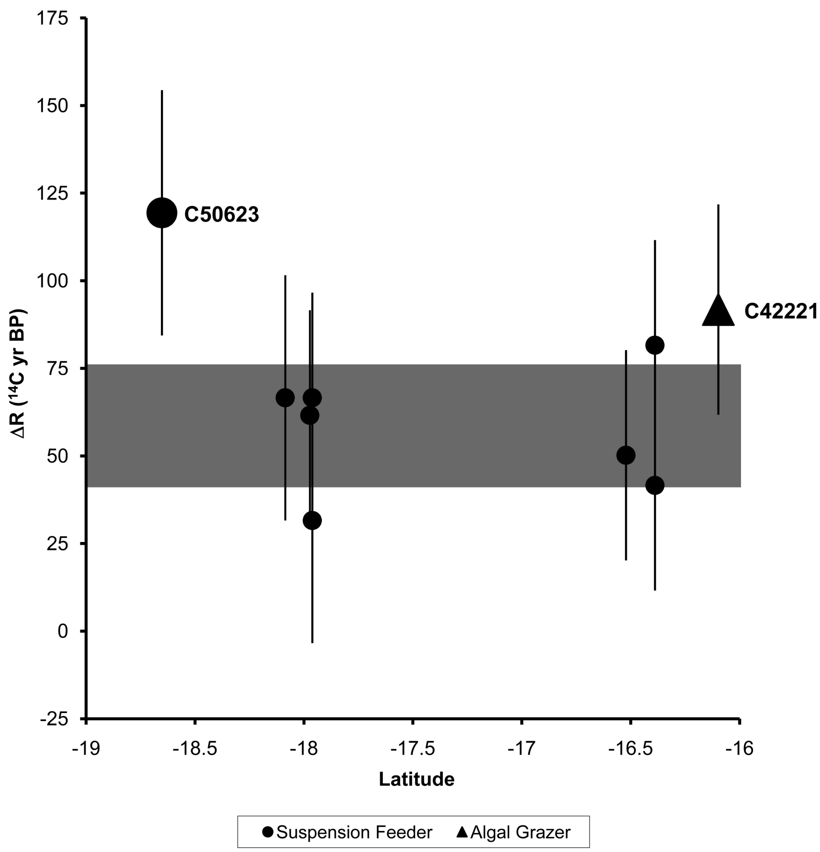

Figure 2 All ΔR values calculated for this project, excluding F28554 (deposit feeder). Oversized markers indicate values excluded from the regional mean. The gray band indicates the new ΔR value of 58 ± 17 ^{14}C yr recommended as a result of this study.

Sample F28554 from Museum Victoria, *Tellina tenuilamellata*, ranked 2, collected from the upper reaches of a tidal creek in an estuarine habitat, produced a much older value than anticipated. The ΔR value is more depleted than any other values documented in the region and more akin to those associated with polar waters or areas with significant upwelling (Stuiver et al. 1986). The reasons for this are currently unclear. The most likely explanation is that the age has been impacted by the *Tellina* specimen deposit feeding on old carbon (Beesley et al. 1998:343). Alternatively, it is possible that the collection date associated with the specimen represents the year that the material was acquired by the collector and given to the museum, rather than its live-collection date (i.e. it may have been collected from an archaeological deposit rather than live-collected). However, the Port George value reported by Bowman (1985a) is also significantly depleted, suggesting the possibility of localized variation in reservoir inputs (Table 1). This value was excluded from the regional ΔR estimate. The chiton, *Acanthopleura spinosa* (C42221), ranked 2, was also not included in the weighted mean as it was from the Buccaneer Archipelago to the northeast of the study area and is an algal grazer. It is not known if this species of chiton is an endolithic grazer, but it certainly grazes upon the rock surface. Although it was excluded, this specimen produced a ΔR value in close agreement with the first ranked specimens from the study area, perhaps indicating that the ΔR for open waters from Broome to the tip of the Dampierland Peninsula at Cape Leveque can reasonably be applied to open-ocean species from the Buccaneer Archipelago. Similarly, specimen C50623 (*Dosinia scalaris*), ranked 2, had an uncertain collection date, but returned a broadly similar, though slightly depleted value.

The regional mean of ΔR = 58 ± 17 ^{14}C yr calculated here conforms with values obtained from Garden Island and Nornalup in southwest Western Australia by Gillespie (1977) and Bowman (1985b), respectively, which return a mean of 71 ± 47 ^{14}C yr ($T' = 0.78$; $\chi^2_{3:0.05} = 7.81$) (Reimer and Reimer 2009). These data confirm that, at least for the recent past, the near-shore waters of the west coast of Australia exhibit generally uniform marine reservoir effects in areas dominated by the South Equatorial and Leeuwin currents. Further studies are required to examine variability in marine reservoir activity through time (e.g. Ascough et al. 2009).

CONCLUSION

Our study confirms Bowman's ΔR value for open coastal waters in the Kimberley region, but as we dated known-age specimens that were suspension feeders from open waters, we were able to refine the ΔR slightly and reduce the error term considerably. Based on the 7 dated specimens ranked 1 from the Broome-Dampierland region, we recommend a ΔR of 58 ± 17 for open coastal waters for this region for specimens dating to the recent past.

We suggest that, where possible, a variety of live-collected specimens should be dated from a single region to examine variability. Ideally, data will be available for both open water and estuarine environments as indigenous people used both environments in prehistory and their shell middens are composed of marine and estuarine shell. Unfortunately, from our search of the major Australian museum collections it is evident that live-collected specimens meeting the above-recommended criteria will not be available for all regions of the Australian coastline.

ACKNOWLEDGMENTS

We thank Chris Rowley (Museum Victoria) for supplying shell specimens for this study and Fiona Petchey (Radiocarbon Dating Laboratory, University of Waikato) and Paula Reimer (Queen's University, Belfast) for advice on ΔR calculations.

REFERENCES

Ascough PL, Cook GT, Dugmore AJ. 2009. North Atlantic marine ^{14}C reservoir effects: implications for late-Holocene chronological studies. *Quaternary Geochronology* 4(3):171–80.

Beesley PL, Ross GJB, Wells A, editors. 1998. *Mollusca: The Southern Synthesis*. Fauna of Australia, Volume 5. Melbourne: CSIRO Publishing. 1250 p.

Bourke P, Hua Q. 2009. Examining late Holocene marine reservoir effect in archaeological fauna at Hope Inlet, Beagle Gulf, north Australia. In: Fairbairn A, O'Connor S, Marwick B, editors. *New Directions in Archaeological Science*. Terra Australis 28. Canberra: ANU E Press. p 175–85.

Bowman GM. 1985a. Oceanic reservoir correction for marine radiocarbon dates from northwestern Australia. *Australian Archaeology* 20:58–67.

Bowman GM. 1985b. Revised radiocarbon oceanic reservoir correction for southern Australia. *Search* 16(5–6):164–5.

Bowman GM, Harvey N. 1983. Radiocarbon dating marine shells in South Australia. *Australian Archaeology* 17:113–23.

CSIRO. 2000. The East Australian Current [WWW document]. Canberra: CSIRO. URL: http://www.marine.csiro.au/LeafletsFolder/37eac/. Accessed 13 October 2006.

Culleton BJ, Kennett DJ, Ingram BL, Erlandson JM, Southon JR. 2006. Intrashell radiocarbon variability in marine mollusks. *Radiocarbon* 48(3):387–400.

Druffel ERM, Griffin S. 1999. Variability of surface ocean radiocarbon and stable isotopes in the southwestern Pacific. *Journal of Geophysical Research* 104(C10):23,607–13.

Dye T. 1994. Apparent ages of marine shells: implications for archaeological dating in Hawai'i. *Radiocarbon* 36(1):51–7.

Fallon SJ, Guilderson TP. 2008. Surface water processes in the Indonesian throughflow as documented by a high-resolution coral $\Delta^{14}C$ record. *Journal of Geophysical Research* 113: C09001, doi:10.1029/2008JC004722.

Forman SL, Polyak L. 1997. Radiocarbon content of prebomb marine molluscs and variations in the ^{14}C reservoir age for coastal areas of the Barents and Kara seas, Russia. *Geophysical Research Letters* 24(8):885–8.

Gillespie R. 1977. Sydney University natural radiocarbon measurements IV. *Radiocarbon* 19(1):101–10.

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

Head J, Jones R, Allen J. 1983. Calculation of the "marine reservoir effect" from the dating of shell-charcoal paired samples from an Aboriginal midden on Great Glennie Island, Bass Strait. *Australian Archaeology* 17:99–112.

Hogg AG, Higham TFG, Dahm J. 1998. ^{14}C dating of modern marine and estuarine shellfish. *Radiocarbon* 40(2):975–84.

Hughen KA, Baillie MGL, Bard E, Beck JW, Bertrand CJH, Blackwell PG, Buck CE, Burr GS, Cutler KB, Damon PE, Edwards RL, Fairbanks RG, Friedrich M, Guilderson TP, Kromer B, McCormac G, Manning S, Bronk Ramsey C, Reimer PJ, Reimer RW, Remmele S, Southon JR, Stuiver M, Talamo S, Taylor FW, van der Plicht J, Weyhenmeyer CE. 2004. Marine04 marine radiocarbon age calibration, 0–26 cal kyr BP. *Radiocarbon* 46(3):1059–86.

Konishi K, Tanaka T, Sakanoue M. 1982. Secular variation of radiocarbon concentration in sea water: sclerochronological approach. In: Gomez ED, editor. *Proceedings of the Fourth International Coral Reef Symposium 1*. Manila: Marine Science Center, University of the Philippines. p 181–5.

Petchey F. 2009. Dating marine shell in Oceania: issues and prospects. In: Fairbairn A, O'Connor S, Marwick B, editors. *New Directions in Archaeological Science*. Terra Australis 28. Canberra: ANU E Press. p 157–72.

Petchey F, Anderson A, Zondervan A, Ulm S, Hogg A. 2008. New marine ΔR values for the South Pacific Subtropical Gyre region. *Radiocarbon* 50(3):373–97.

Reimer PJ, Reimer RW. 2009. Marine Reservoir Correction Database [WWW document]. Belfast: 14CHRONO Centre, Queen's University of Belfast. URL: http://calib.org/marine. Accessed 15 November 2009.

Rhodes EG, Polach HA, Thom BG, Wilson SR. 1980. Age structure of Holocene coastal sediments: Gulf of Carpentaria, Australia. *Radiocarbon* 22(3):718–27.

Stuiver M, Braziunas TF. 1993. Modelling atmospheric ^{14}C influences and ^{14}C ages of marine samples to 10,000 BC. *Radiocarbon* 35(1):137–89.

Stuiver, M, Pearson GW, Braziunas T. 1986. Radiocarbon age calibration of marine samples back to 9000 cal yr BP. *Radiocarbon* 28(2B):980–1021.

Ulm S. 2002. Marine and estuarine reservoir effects in central Queensland, Australia: determination of ΔR values. *Geoarchaeology* 17(4):319–48.

Ulm S. 2006. Australian marine reservoir effects: a guide to ΔR values. *Australian Archaeology* 63:57–60.

Ulm S, Petchey F, Ross A. 2009. Marine reservoir corrections for Moreton Bay, Australia. *Archaeology in Oceania* 44(3):160–6.

Ward GK, Wilson SR. 1978. Procedures for comparing and combining radiocarbon age determinations: a critique. *Archaeometry* 20(1):19–31.