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Late Holocene marine radiocarbon reservoir correction for the south and east coast of South Africa

Matjie L Maboya^{a,b*}, Michael E Meadows^{a,e}, Paula J Reimer^{c,d}, Björn C Backeberg^{f,g,h} and Torsten Haberzettl^b

Author Addresses

a) Department of Environmental & Geographical Science, University of Cape Town, Private Bag X3, Rondebosch 7701, South Africa

b) Physical Geography, Institute of Geography, Friedrich Schiller University Jena, Löbdergraben 32, 07743 Jena, Germany

c) School of Natural and Built Environment, Queen's University Belfast, Belfast BT7 1NN, United Kingdom

d) Centre for Climate, the Environment & Chronology (14CHRONO), School of Natural and Built Environment, Queen's University Belfast, Belfast BT7 1NN, United Kingdom

e) School of Geographic Sciences, East China Normal University, 500 Dongchuan Road, Shanghai 200241, China

f) Coastal Systems, Natural Resources and the Environment, Council for Scientific and Industrial Research (CSIR), Jan Celliers Road, Stellenbosch 7600, South Africa

g) Nansen-Tutu Centre for Marine Environmental Research, University of Cape Town, Private Bag X3, Rondebosch 7701, South Africa

h) Nansen Environmental and Remote Sensing Center, Thormøhlens 47, 5006, Bergen, Norway

*Corresponding Author: Matjie L Maboya mmaboya09@alaalumni.org

ABSTRACT

The marine reservoir effect is the difference in radiocarbon (^{14}C) between the atmosphere and the marine surface ocean. In order to overcome the dating errors induced, it is necessary to correct marine radiocarbon ages for this effect. ΔR is the difference between the marine ^{14}C age and the marine calibration curve based on an ocean-atmosphere box diffusion model which accounts for the time delay in diffusion of carbon into the ocean from the atmosphere and biosphere. This global assessment however requires computation of a regional ΔR value for calibration to cater for studies based on a local scale. In this paper the marine reservoir effect is assessed for the south and east coast of South Africa using radiocarbon dating on pre-1950 marine shells of known age. The resultant ΔR values enable a more complete understanding of the marine reservoir effect along the south and east coastal zone of South Africa. Radiocarbon age determinations were conducted on 15 shell samples of known age and the results used to calculate regional marine reservoir correction values for the region. The east coast has a weighted mean ΔR of 121 ± 16 ^{14}C years, while the south coast has a weighted mean ΔR of 187 ± 18 ^{14}C years.

KEYWORDS:

Chronology, radiocarbon dating, marine reservoir effect, reservoir correction, South Africa

INTRODUCTION

Quaternary palaeoenvironmental conditions in southern Africa remain poorly resolved due to the spatially and temporally fragmented nature of available evidence. The reconstruction of longer-term palaeoclimatic changes is, however, important because southern Africa is exposed to dynamics of both tropical and temperate climate regimes due to its latitudinal position (Carr, et al., 2006; Chase, et al. 2013). Southern Africa is influenced by a complex of tropical, subtropical and temperate climate systems arising from its geographical location and its position in relation to the Indian and Atlantic oceans. A deeper understanding of how climate and other features of the environment have varied during the late Quaternary is significant for a number of reasons, including the fact that the region represents a key locality in the archaeology of behaviourally modern humans and that the elucidation of the longer-term dynamics of its various climate controls is important to developing more reliable climate models. Indeed, the volume and quality of research into reconstruction of palaeoenvironmental conditions in the Quaternary of the region has increased markedly within the last decade in response to the recognition of its significance. Reconstructions are based on traditional proxies, such as pollen (e.g. Quick et al., 2016), diatoms (e.g. Kirsten and Meadows, 2012) and sedimentological parameters (e.g. Reinwarth et al. 2013) from wetland and lake sediments, as well as novel evidence, including a range of biological and chemical characteristics of rock hyrax middens (e.g. Chase et al., 2013). Other investigations are underway, including those carried out recently within the RAIN project (Regional Archives for Integrated iNvestigations), which is a multidisciplinary and multi-institutional collaboration that aims to explore evidence from terrestrial and offshore sediments of changing climate and associated environmental conditions during the late Quaternary in southern Africa (Haberzettl 2014). While these reconstructions have greatly improved understanding of environmental changes in the region during the Quaternary, the establishment of reliable chronologies, which are crucial for every palaeoenvironmental reconstruction, remain a key challenge for sedimentary sequences (Wündsche et al., 2016a). Several studies that link terrestrial and marine records to reconstruct palaeoclimates in the region have ensued, and therefore need to consider marine reservoir corrections (e.g. Wündsche et al., 2016a,b; Zhao et al., 2016).

Central to such studies is obtaining accurate age determination of the samples and, therefore, a reliable and robust chronology. This paper aims to approximate the marine reservoir effect for the southeast coastal region of South Africa as a step to better contextualizing results of the numerous late Quaternary palaeoenvironmental studies currently underway. ΔR is the regional marine reservoir offset from the global marine calibration curve and needs to be quantified in order to correct for the local conditions that affect diffusion of radiocarbon into the surface ocean (Stuiver et al., 1986). Reimer and Reimer (2001) remarked on the lack of reservoir correction data for most of Africa, and until now there have been very few such

studies (Dewar et al., 2012; Southon et al. 2002; Wündsche et al., 2016a). Dewar et al. (2012) highlighted the need to conduct a regional reservoir correction study on the south coast of South Africa similar to the one they carried out for the west coast. The results reported here therefore respond to the need for additional ΔR estimates for the oceans around the African continent. The paper presents results of radiocarbon dating of 15 known-age (pre-1950) shell samples in order to derive a marine reservoir correction value for coastal regions of South Africa, for which hitherto there has been an inadequate database to enable radiocarbon age adjustment on sediments from coastal and marine sources. The samples yield results for two distinctive zones relating to the south and east coasts of South Africa and represent a sound data set on which to base ΔR values for a stretch of coastline extending over 1500 km between Richards Bay and Jeffrey's Bay.

MARINE RESERVOIR EFFECT

The marine reservoir correction values differ spatially and temporally due to differences in ocean currents, upwelling and latitudinal atmospheric variation (Ascough et al., 2005; 2006). The difference between the local reservoir age (which is specific to a region and determined using known-age marine samples) and the modelled global marine reservoir age is known as the ΔR value (Stuiver et al. 1986; Stuiver and Braziunas 1993; Stuiver, et al., 1998; Southon, et al., 2002) and is calculated as follows:

$$\Delta R(t) = R_s(t) - R_g(t) \quad (1)$$

Where:

$R_s(t)$ = regional reservoir age at a specific time period;

$R_g(t)$ = modelled radiocarbon age of ocean surface water;

$\Delta R(t)$ = reservoir offset for a specific location at time t , usually determined using known-age marine samples.

The use of a marine reservoir correction value, ΔR , is fundamental to the construction of archaeological and palaeoenvironmental chronologies in coastal or marine contexts. ΔR can be positive or negative for a specific location, and empirical studies of specific locations are required in order to determine the sign and the magnitude (Stuiver and Braziunas, 1993).

METHODOLOGY

There are three main methods used to determine ΔR values using marine samples, viz. using 'paired' shell/terrestrial samples (Wündsche et al., 2016a), known-age marine samples and onshore/offshore tephra isochrons (Ascough et al., 2005). Radiocarbon dating of 'paired' samples involves collecting charcoal/terrestrial and shell/marine samples from locations that

are assumed to have adequate chronological integrity. The method employed in this paper bases ΔR calculations on the radiocarbon dating of marine shells of known age which have been collected pre-AD 1950 shortly after death and, while there are some constraints indicated by this method (Ascough et al., 2005), the advantage of using known-age marine samples is that it does not require comparison between terrestrial samples and marine shells (as is the case with paired samples), therefore reducing additional uncertainties introduced through dealing with two different sets of radiocarbon ages (Ulm, 2002). Furthermore, there are no post-depositional issues or problems with bioturbation when using samples of known collection age (Ulm, 2002). ΔR determination in this case relies, firstly, on the assumption that the date of original collection approximates the date of death of the organism and, secondly, on appropriately accurate museum curation and treatment prior to radiocarbon dating.

Location of sample sites

Only the west coast region of South Africa had been adequately studied in terms of marine reservoir corrections (Dewar et al. 2012). The choice of the southeast coastal region as a focus for this study was driven by the need to obtain accurate ΔR values due to the range of ongoing Quaternary palaeoenvironmental studies in southern Africa that are reliant on ^{14}C dating for chronology, more especially in relation to the ongoing RAIN project (Haberzettl et al., 2014). The general absence of limestone bedrock along the southeast coast is considered an advantage in this study as this reduces the likelihood of systematic error in the results through the incorporation of ^{14}C -depleted material into the food chain. Carboniferous bedrocks have been shown to adjust the apparent radiocarbon age of the Hawaiian coast by up to +620 years (Dye, 1994). Therefore, non-filter feeding bivalves collected from areas where there is underlying limestone geology should be treated with caution (Reimer and Reimer, 2001). The search for a wide selection of bivalve material collected before AD 1950 led the authors to collections curated at the Natal Museum in Pietermaritzburg, South Africa, where there exists a substantial number of marine bivalve samples that meet the necessary criteria for the south and east coasts of South Africa (Table 1). Samples for radiocarbon dating were chosen in order to produce a relatively even spatial distribution along the coast based on their original collection localities (Figure 2).

Table 1: Locations of sample points used in this study (A-O). 'Acc no' is the Museum reference for the sample

ID	Acc No	Family	Genus	Species	Locality	Latitude S	Longitude E
A	2349	PTERIIDAE	<i>Pinctada</i>	<i>nigra</i>	Nonoti	29° 18' 46.5402"	31° 24' 41.5974"
B	3299	PECTINIDAE	<i>Pecten</i>	<i>sulcicostatus</i>	Algoa Bay, off Bird Island	33° 58' 1.1994"	26° 19' 01.2000"
C	B7078	VENERIDAE	<i>Venus</i>	<i>verrucosa</i>	Port Alfred	33° 36' 00.0000"	26° 53' 59.9994"

D	2901	LUCINIDAE	<i>Lucina</i>	<i>carnosa</i>	East London	33° 00' 33.5658"	27° 55' 31.4862"
E	4520	ARCIDAE	<i>Arca</i>	<i>avellana</i>	Kosi Bay	26° 54' 5.7594"	32° 52' 00.5694"
F	2800	MERITRICINAE	<i>Tivela</i>	<i>valae</i>	Scottburgh	30° 17' 13.2966"	30° 45' 36.4068"
G	4494	PECTINIDAE	<i>Pecten</i>	<i>benedictus cf erythraeensis</i>	Durban	29° 50' 55.9788"	31° 02' 21.1626"
H	B7070	MACTRIDAE	<i>Mactra</i>	<i>glabrata</i>	Kabeljouw's River	34° 00' 12.4488"	24° 55' 59.4186"
I	4558	ARCIDAE	<i>Barbatia</i>	<i>foliata</i>	Shelley Beach, Izotsha	30° 48' 02.3070"	30° 24' 51.3642"
J	A1034	OSTREIDAE	<i>Crassostrea</i>	<i>margaritacea</i>	Umhlali	29° 30' 16.3794"	31° 14' 24.1002"
K	B9981	DONACIDAE	<i>Donax</i>	<i>madagascariensis</i>	Coffee Bay	31° 58' 57.1728"	29° 09' 20.3178"
L	2379	PINNIDAE	<i>Atrina</i>	<i>vexillum</i>	Durban	29° 50' 47.6730"	31° 02' 19.7736"
M	B7034	PINNIDAE	<i>Pinna</i>	<i>muricata</i>	Umgazi River Mouth	31° 40' 59.9880"	29° 45' 00.0000"
N	9534	SOLENIIDAE	<i>Solen</i>	<i>cylindraceus</i>	Richards Bay	28° 48' 04.3734"	32° 03' 37.4112"
O	1896	VENERIDAE	<i>Dosinia</i>	<i>lupinus orbigny</i>	Algoa	33° 49' 36.3678"	25° 47' 42.9462"

Figure 1: Locations of known-age marine shell samples A-O used in the analysis. Localities used in Wüdsch et al. (2016a) are labelled P and Q, the Natal location for Southon et al. (2002) is labelled R, while Cape of Good Hope sample is off the map, located about 300 km

west of Mossel Bay. Colour scheme shading from white to black correlates with increasing ΔR values. Descriptions for samples (A-O) can be found in Table 1

Species selection

Marine molluscs offer the most appropriate material in providing the required estimate of ΔR because of their sedentary habits (Ascough et al., 2005). The challenge with migratory species is that they may represent carbon influences of several locations with different background ^{14}C content (Ascough et al., 2005). Hence, only, marine filter-feeding bivalves were selected as the most suitable object for this research as they are not migratory. The two pre-bomb samples from Wündsche et al. (2016) are gastropods (*Ocenebra fenestrata* from Mossel Bay is a carnivore and *Drillia caffra* from Jefferys Bay is a deposit feeder) but we have included them as they are in agreement with our filter-feeding samples. For the two samples from Southon et al. 2002, the Cape of Good Hope sample is a filter-feeding bivalve *Venerupis corrugate* but the feeding habitat of the bivalve *Marcia paupercula* from Natal is not known.

Harkness (1983) stated that a requirement for known age samples from museums is live collection, as well as thorough and accurate recording of locality and date of collection and storage. The Natal Museum, which is the source of samples used in this study, has robust standards of curation and record-keeping. Yoneda et al. (2000) highlight the importance of collecting material where there is evidence that the organism was collected live. For this study, only one sample (#9534) contained unequivocal evidence of live collection, as the body tissues were preserved within the shell. Live collection can also reasonably be inferred from articulated bivalves and attachment of the resilium (Berkman and Forman, 1996), which was the case for sample #9534. The other samples are assumed to have been collected a short time after death as the condition of the shells in question suggested that this was the case. All of the bivalves were unweathered and had both shells still in place, or available in the collection; this typically indicates collection at or shortly after death (Reimer and McCormac, 2002). Filter-feeding bivalve samples were collected for this research using only species that are known to reside predominantly in marine environments. Additional samples meeting the necessary criteria were not selected either because a) they represented the last remaining sample in the collection, b) it was the original sample used to describe/define the species type or c) were too small to be subsampled for radiocarbon dating. All samples had been collected in the 'pre-bomb' era, dating from 1905 to 1939, as documented in the museum record.

Sample preparation

Following sample selection from the Natal Museum Archives, the samples were mechanically prepared using a Dremel® micro-drilling tool. For all samples, preliminary external brushing was conducted to remove any visible surficial debris. Following this, a section of roughly 0.5 cm x 0.5 cm of the outermost 2-3 growth increments was excavated from each sample and stored for shipping. Sample preparation and radiocarbon dating took place at the ^{14}C CHRONO

Centre in the Queen's University Belfast. The shell samples were washed in deionized water in an ultrasonic bath then air-dried and approximately 12 mg of shell was placed in a septum-sealed vial (Vacutainer). The samples were then etched with a quantity of 0.18 ml of 1% HCl for a 12 mg shell sample to remove approximately 25% of the initial weight and then rinsed again with deionized water. Following the method of Santos et al. (2004), the vials were sealed, evacuated and then injected with 85% phosphoric acid (H_3PO_4) and placed on a heating block at 60°C for 30 min to evolve carbon dioxide, which was cryogenically purified and transferred on the graphite line to a culture tube containing pre-baked iron. Following the method of Vogel et al. (1984), hydrogen gas was added and the tube was heated to 560°C for four hours. The graphite was then pressed in aluminium holders and analysed on a 0.5 MV National Electrostatics Corporation Compact Accelerator Mass Spectrometer (AMS). The sample $^{14}\text{C}/^{12}\text{C}$ ratio was background corrected and normalised to the HOXII standard (SRM 4990C; National Institute of Standards and Technology). The $^{14}\text{C}/^{12}\text{C}$ ratio was corrected for isotopic fractionation using the AMS-measured $\delta^{13}\text{C}$, which includes natural and machine fractionation (and therefore is not included in the text). The ^{14}C age and one standard deviation were calculated using the Libby half-life (5568 years) following the conventions of Stuiver and Polach (1977).

RESULTS AND DISCUSSION

The ΔR values were calculated using the marine calibration curve (MARINE13, Reimer et al., 2013) and computed on the basis of the following equation

$$\Delta R = \text{shell sample } ^{14}\text{C age} - \text{MARINE13 curve age} \quad (1)$$

The uncertainty in ΔR is taken as the standard error in the ^{14}C age of the sample without including the calibration uncertainty that is taken into account by the calibration programs (Table 2).

Table 2: ΔR values as calculated for samples A-O

ID	Accession #	Genus	Species	Locality	Year collected (AD)	^{14}C age BP	Marine13 curve age	ΔR (^{14}C yrs)	1 σ uncertainties
A	2349	<i>Pinctada</i>	<i>nigra</i>	Nonoti	1911	547	448	99	± 26
B	3299	<i>Pecten</i>	<i>sulcicostatus</i>	Algoa Bay, off Bird Island	1920	653	448	205	± 27
C	B7078	<i>Venus</i>	<i>verrucosa</i>	Port Alfred	1928	660	452	208	± 26
D	2901	<i>Lucina</i>	<i>carnosa</i>	East London	1905	589	449	140	± 26
E	4520	<i>Arca</i>	<i>avellana</i>	Kosi Bay	1905	575	449	126	± 29
F	2800	<i>Tivela</i>	<i>valae</i>	Scottburgh	1913	568	448	120	± 24
G	4494	<i>Pecten</i>	<i>benedictus cf erythraeensis</i>	Durban	1939	580	459	121	± 24
H	B7070	<i>Mactra</i>	<i>glabrata</i>	Kabeljouws River	1912	670	448	222	± 26
I	4558	<i>Barbatia</i>	<i>foliata</i>	Shelley Beach, Izotsha	1930	570	453	117	± 25
J	A1034	<i>Crassostrea</i>	<i>margaritacea</i>	Umhlali	1941	641	461	180	± 28
K	B9981	<i>Donax</i>	<i>madagascariensis</i>	Coffee Bay	1920	649	448	201	± 25
L	2379	<i>Atrina</i>	<i>vexillum</i>	Durban	1911	641	448	193	± 28
M	B7034	<i>Pinna</i>	<i>muricata</i>	Umgazi River Mouth	1941	539	461	78	± 26
N	9534	<i>Solen</i>	<i>cylindrace us</i>	Richards Bay	1923	716	450	266	± 26
O	1896	<i>Dosinia</i>	<i>lupinus</i>	Algoa	1911	799	448	351	± 28

Considering all samples from this study (Table 2), the ΔR data span a range from 78 ± 26 to 351 ± 28 ^{14}C yrs; however the ΔR values do not pass a chi-squared test ($T' = 105.0$, $\chi^2(0.05) = 26.3$). Overall, ΔR values in the south of East London are larger than those in the East. We therefore split the data into two sub-groups: South and East, split at East London, between Sample C and Sample D (Figure 1). According to Reimer and Reimer (2001), samples with ΔR values that are very markedly greater than the mean should be excluded from any regional mean calculation because they may not have been collected within a sufficiently short time following death. Sample O ($\Delta R = 351 \pm 28$), collected from Algoa Bay, has a ΔR value almost 100 years greater than many of the others (Table 2) and so exclusion was deemed appropriate. Exclusion of outlier sample O from the south coast dataset results in a pass on the chi-squared test and produces a weighted mean ΔR value of 194 ± 23 (Table 3a) where the uncertainty is given as the standard error for predicated values (Russell et al. 2011). A similar exercise for the east coast samples identifies sample N (266 ± 28) as an outlier as well as samples K and L (Table 3b); their exclusion lowers the weighted mean ΔR of the east coast samples to 119 ± 15 .

In order to test whether the ΔR values of the south coast are larger than the east coast, we used a one-tailed t-test assuming unequal variances with a null hypothesis that they are the same. The hypothesis was disproved at 95% confidence limits with probability = 0.0135 and only slightly less significant ($p = 0.140$) assuming equal variances. Using two-tailed t-tests, which imply the difference between the ΔR values of two coasts could be the opposite direction, results in $p = 0.0269$ and $p = 0.0281$ for unequal and equal variances, respectively. Therefore, according to the results outlined, ΔR values from the south and east coastal regions represent statistically significant sub-sets when evaluated with a t-test.

Table 3a, b: Geographical distribution of two populations of ΔR values from this study for the south and east coastal regions and correlating chi-tests with weighted means giving the uncertainty as the standard error of predicated values.

3a

South Sample Geographic ID	ΔR (^{14}C yrs)	1 σ uncertainties
B	205	27
C	208	26
H	222	26
D	140	26
Chi-test for South (all samples except O)		
T'	$\chi^2(.05)$	Passes?
5.93	7.8	Yes
Weighted Mean		
194 ± 23		

3b

East Sample Geographic ID	ΔR (^{14}C yrs)	1 σ uncertainties
A	99	26
E	126	29
F	120	24
G	121	24
I	117	25
L	193	28
K	201	25
M	78	26
C	208	26
J	180	28
Chi-test for East (all samples excluding N)		
T'	χ^2 (.05)	Passes?
21.91	15.5	No
Chi-test for East excluding N, L & K		
T'	χ^2 (.05)	Passes?
7.90	12.6	Yes
Weighted Mean		
119 $\pm$ 15		

Prior to this study, only three ΔR studies have been reported across the entire coastline of South Africa (Southon et al., 2002; Dewar et al., 2012; Wündsche et al., 2016) (Table 4), with the study by Dewar et al. (2002) confined to the west coast. The ΔR value determined for the east coast by Southon et al. (2002) was based on a marine shell collected in Kwa-Zulu Natal that yielded a ΔR value of 213 ± 57 (recalculated with MARINE13) (Sample R) which accords within the uncertainty with the ΔR values presented here for this eastern part of the South African coast. A pooled mean ΔR for the East coast, inclusive of Sample R (Southon et al., 2002) and ΔR values from this study is 121 ± 16 . For the south coast, Southon et al. (2002) documented a ΔR value of 224 ± 51 (recalculated with MARINE13) from a bivalve that was collected in AD 1820 from the Cape of Good Hope area, while Wündsche et al. (2016a) recorded ΔR values of 134 ± 38 (Sample P) and 161 ± 38 (Sample Q). If these previous values (Table 4) are analysed along with our south coast samples they are statistically the same ($T'=9.12, \chi^2 = 12.6$). We therefore include these previous measurements in our weighted mean for the south coast. The resultant mean ΔR for the south coast, inclusive of Sample P, Q and R is 187 ± 18 .

Table 4: ΔR values from prior studies in the region

	Reference	GENUS	Species name	Common name	Locality	Latitude	Longitude	ΔR	Standard Error	Sub-region
P	Wündsche et al., 2016	<i>Muricidae</i>	<i>Ocenebra fenestrata</i>	gastropod	Mossel Bay	39° 09' 28.8000"	22° 06' 46.7994"	134	38	south
Q	Wündsche et al., 2016	<i>Drillidae</i>	<i>Drillia caffra</i>	gastropod	Jeffrey's Bay	34° 02' 34.7994"	24° 53' 52.7994"	161	38	south
R	Southon et al., 2002	<i>Tapes</i>	<i>Marcia paupercula</i>	bivalve	Near Durban	30°	31.1°	213*	57	east
S	Southon et al., 2002	<i>Venerupis</i>	<i>corrugatus</i>	bivalve	Cape of Good Hope	34.5°	18.6°	224*	51	south

*Recalculated with Marine13

Both the east and south coast weighted mean ΔR values are larger than the global ocean average (0 ^{14}C yrs by definition). However, our results indicate higher ΔR values to the south, which suggests that waters with lower ^{14}C content compared to the northern region are found here. Immediately south of East London the continental shelf widens. As the continental shelf widens, the Agulhas Current, which flows southwestward along the shelf break, is forced away from the coast inducing divergence and cyclonic circulation inshore of the Agulhas Currents resulting in upwelling (Gill and Schumann, 1979). Applying the theory from Gill and Schumann (1979), Lutjeharms et al. (2000a) explain the presence of a semi-permanent upwelling cell (surface water cooler than 17°C) inshore of the Agulhas Current, off Port Alfred (33.5°S). Additionally, along the south coast, wind-driven upwelling combined with divergent flow driven by the Agulhas Current bring colder water onto the Agulhas Bank (Lutjeharms et al., 2000a). The colder upwelled water masses are sourced from radiocarbon depleted South West Indian Central waters from depths of >500 m, which have been found to mix with surface waters (Stuiver and Ostlund, 1983; Lutjeharms et al., 2000a). North of East London, the shelf is consistently narrow, and the northern Agulhas Current follows a stable trajectory, meandering less than 15 km from its mean path (Gründlingh, 1983). The narrow continental shelf and stable trajectory of the Agulhas Current inhibits the possibility for persistent upwelling of ^{14}C depleted waters, which may explain the lower ΔR to the north.

In addition to providing insight into why there are two ΔR populations, the regional oceanography may also explain why Sample N, near Richards Bay, has an older radiocarbon age than the other samples in the region. Lutjeharms et al. (1989) describe a persistent topographically-induced upwelling cell off Richards Bay due to a widening of the continental shelf, similar to the upwelling dynamics occurring near Port Alfred. However, contrary to Port Alfred whose upwelling waters are derived from the upper to middle layers of the South Indian Central Water (Lutjeharms et al., 2000a), there is no conclusive evidence of substantial amounts of deeper South Indian Ocean Central Waters being upwelled onto the shelf of the Natal Bight (Lutjeharms et al., 2000b), rather the circulation over most of the southern parts of the Natal Bight appear to be derived from Agulhas Current waters periodically encroaching

onto the Bight, reaching as far as Durban, possibly explaining the outlier associated with Sample L.

CONCLUSIONS

Marine reservoir correction values for the south and east coastal regions of South Africa have hitherto been based on a very small sample size. This paper reports that the south coast has higher ΔR values than the east coast, and supplements those of Dewar et al. (2012) for the west coast. Further studies on the hydrography of the south and east coasts may help to cast further light on this finding, and increase both the volume and quality of reservoir correction data for the region. The determined ΔR values for the south and east coasts of South Africa indicate two distinctive geographical sub-regions. The east coast has a mean ΔR of 121 ± 16 years, while the south coast has a mean ΔR of 187 ± 18 years. Both these ΔR values are important for ongoing and future Late-Quaternary palaeoenvironmental studies on marine sediments, or marine-influenced sediments from the region.

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LIST OF FIGURES

Figure 1: Locations of known-age marine shell samples A-O used in the analysis. Localities used in Wündsche et al. (2016a) are labelled P and Q, the Natal location for Southon et al. (2002) is labelled R, while Cape of Good Hope sample is off the map, located about 300 km west of Mossel Bay. Colour scheme shading from white to black correlates with increasing ΔR values. Descriptions for samples (A-O) can be found in Table 1

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