Ten $\Delta R$ values recently obtained from Torres Strait (AINGRA06181) point to significant variation in marine reservoir activity, with lower values in the east (-101±39) and higher values in the west (-32±20). These results were unexpected given the previous value of +50±47. The reasons for such marked variability are unclear but have considerable implications in terms of constructing archaeological and palaeoenvironmental chronologies. This project will enhance preliminary findings by increasing the number, geographical spread and targeted taxa of $\Delta R$ values. Results will have direct benefits to Quaternary scientists working across the region in establishing robust understandings of marine reservoir effects.

**PROGRESS REPORT and RESEARCH OUTCOMES**

Ten live-collected shell specimens with excellent provenance data were identified in the Australian Museum malacology collection from across Torres Strait and western Cape York Peninsula to expand the findings of AINGRA06181. Four specimens were from Mer (Murray Island) in eastern Torres Strait, one each from Albany Passage and Ngiangu (Booby Island) in western Torres Strait and four from southwest of Mapoon on the northwest coast of Cape York Peninsula. Nine of the 10 samples were suspension-feeders, avoiding problems sometimes encountered with shellfish with other dietary preferences (e.g. Hogg et al. 1998; Petchey 2009; Tanaka et al. 1986). The single herbivore/omnivore was a *Nerita undata* from Booby Island where no alternative specimens were available for analysis.

The 10 AMS radiocarbon dates obtained in this project were used to calculate corresponding $\Delta R$ values for each dated specimen (Appendix A, Run 319). Historical ages of shell samples (i.e. year of death) were converted to equivalent global marine model ages using the MARINE04 calibration dataset (Hughen et al. 2004). For years not shown, values were interpolated between available data points. $\Delta R$ values were calculated by deducting the equivalent global marine model age of the age of death of the shell sample from the $^{14}$C age of the shell sample. The standard deviation of the $\Delta R$ value is the one-sigma estimate of uncertainty in the conventional radiocarbon age of the shell sample (following Reimer and Reimer 2009).

The pooling statistics presented in Appendix B are based on Mangerud et al. (2006: 3241) where the Chi squared ($\chi^2$) test is used to test the internal variability in a group of $\Delta R$ values. If $\chi^2/(n-1) > 1$ the group has additional variability beyond measurement uncertainties, and the additional variance ($\sigma_{\text{ext}}$) and uncertainty are calculated and applied to the $\Delta R$. The additional variance ($\sigma_{\text{ext}}$) is obtained by subtracting the $^{14}$C measurement variance from the total population variance and obtaining the square root; therefore $\sigma_{\text{ext}} = \sqrt{(\sigma_{\text{pop}}^2 - \sigma_{\text{meas}}^2)}$. Any uncertainty including
additional variance is calculated by $\sqrt{(E^2 \text{\scriptsize pooled+}\sigma^2 \text{\scriptsize ext})}$. When $\chi^2/(n-1)$ is $\leq 1$ the weighted mean is used (see Mangerud et al. 2006:3241-3242 for details).

Results were compared against $\Delta R$ values calculated in AING06181 and against previous values available for the region (Appendix A). ANSTO Investigator Geraldine Jacobsen identified an error in the laboratory sampling of the shells submitted for AING06181 Run 279. Instead of sampling a small section of shell on the margin at the highest part of the growth axis of each valve to date the time of death as closely as possible, a piece of shell was broken with pliers, often including older parts of the shell closer to the umbo. Dr Jacobsen offered to redate the 10 specimens adopting the protocol specified in the original laboratory submission forms. Eight of these specimens were redated in Run 317. Two of the original specimens (OZJ-242, OZJ-249) were not redated as they were small Nerita undata univalves where the margin had been appropriately sampled. Results from the redating of AING06181 Run 317 were made available on 6 November 2008. Results for AING08063 Run 319 were received on 3 December 2008.

When the eight results from AING06181 Run 317 were compared against the original Run 279 ages all but one sample returned an older age, significantly older in three cases. The older ages returned in Run 317 are partly attributed to the use of a different blank correction across the three runs. Dates from Runs 279 and 317 were recalculated using a common chemistry blank that was used in the processing of data from Run 319. This blank supersedes the blank that was previously used in Run 279 and is only marginally different from the blank that had been used in Run 317. The new calculations lead to a slight increase in $\text{pMC}$ values for Run 279 (i.e. older radiocarbon ages) compared with the originally released data. The revised data reduces the apparent age gap between the different sample batches; however, these differences are consistent and within the error of the measurement. The recalculated values were made available on 12 January 2009 and finalised on 19 January 2009 after some inconsistencies in reporting were identified in the recalculated data.

The recalculated data to a common blank left two samples from Mer with significantly different dates on the same valves between Runs 279 and 317 (Table 1).

Table 1. Valves returning significantly different ages between Runs 279 and 317.

<table>
<thead>
<tr>
<th>Run</th>
<th>Lab. No.</th>
<th>Species</th>
<th>$^{14}$C Age yr BP</th>
<th>$\Delta R$ $^{14}$C yr</th>
<th>$\Delta R$ $\sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>279</td>
<td>OZJ-245/A</td>
<td>Arca ventricosa</td>
<td>325</td>
<td>-123.8</td>
<td>30</td>
</tr>
<tr>
<td>317</td>
<td>OZJ-245/B</td>
<td>Arca ventricosa</td>
<td>445</td>
<td>-3.8</td>
<td>45</td>
</tr>
<tr>
<td>279</td>
<td>OZJ-247/A</td>
<td>Paphies striata</td>
<td>385</td>
<td>-63.8</td>
<td>35</td>
</tr>
<tr>
<td>317</td>
<td>OZJ-247/B</td>
<td>Paphies striata</td>
<td>480</td>
<td>31.2</td>
<td>30</td>
</tr>
</tbody>
</table>

Intrashell variability in $^{14}$C activity could explain some this variability. For example, Culleton et al. (2006) documented a shell collected in AD 1936 from Santa Barbara with a difference of 220 years between AMS samples at 6mm and 12mm from the edge, with the 12mm sample being younger. Culleton et al. (2006) related these differences to variability in upwelling, mixing and terrestrial run-off. Figure 1 shows the three dates available for conjoining valves of Arca ventricosa from Mer obtained in Runs 279, 317 and 319. Dates for OZL-275 Run 319 and OZJ-245 Run 317 from the edge-margin of opposing valves are not statistically different. However, the ages for OZJ-245 Run 279 and OZJ-245 Run 279, both from the right valve, are significantly different. It is possible that the radiocarbon activity in this bivalve documents variability in the local marine carbon reservoir through time; however, owing to uncertainty in the exact location of the dated sample from material in Run 279 it is difficult to pursue this line of enquiry without further controlled analyses across the growth axis of the valve. Only final results are discussed below, with the eight initial ages obtained in AING06181 Run 279 excluded from further consideration.
Preliminary assessment of the $\Delta R$ values point to variation in marine reservoir activity across the Torres Strait region, with more enriched values on the northwest coast of Cape York Peninsula (Appendix B). The 25 $\Delta R$ values now available for the Torres Strait region (including the five previous values obtained by Gillespie 1977 and Rhodes et al. 1980) are statistically different with an error-weighted mean with external variance of $\Delta R = -54\pm 58$. Following the recommendation of a number of studies (e.g. Hogg et al. 1998; Petchey 2009; Tanaka et al. 1986) to rely primarily on suspension feeders in calculating $\Delta R$ values, pooling the 15 results obtained on suspension feeders in AINGRA06181 and AINGRA08063 results in a statistically different error-weighted mean with external variance of $\Delta R = -63\pm 44$.

In light of the very different oceanographic conditions across Torres Strait and the Gulf of Carpentaria, it is useful to consider results in three groups: eastern Torres Strait (samples from Mer) and western Torres Strait (samples from Albany Passage, Great Woody Island and Ngiangu).

The 10 values available from Mer in eastern Torres Strait are statistically different. Excluding the values obtained on the carnivore Melo amphora and grazing gastropods and algae grazers Nerita undata and Trochidae niloticus respectively, leaves seven suspension feeders which return an error-weighted mean with external variance of $\Delta R = -43\pm 55$. Melo are carnivores which have been identified as potentially problematic for $\Delta R$ calculation as ingested organic carbon from diverse sources can become incorporated into shell structures through metabolic action (Petchey 2009; see also Hogg et al. 1998; Tanaka et al. 1986). This has been found to be a particular problem in limestone-dominated areas (Anderson et al. 2001; Dye 1994), but could also occur in areas with fossil and/or sub-fossil corals (Petchey 2009).

If we apply the same chronometric hygiene protocol to the western Torres Strait samples, excluding the two results based on Nerita undata from Ngiangu, the resulting subregional western Torres Strait weighted mean with external variance based on four suspension feeders is $\Delta R = -57\pm 24$. Given that there is no limestone in the Ngiangu area it might be useful to incorporate the two nerite values into the subregional mean, resulting in a slightly different value of $\Delta R = -63\pm 34$.

The four suspension feeders from southwest of Mapoon on northwest Cape York Peninsula show the greatest enrichment, resulting in an error-weighted mean with no external variance of $\Delta R = -103\pm 16$.

In summary, the $\Delta R$ values proposed here of $-63\pm 44$ for the Torres Strait region, $-43\pm 55$ for eastern Torres Strait subregion, $-57\pm 24$ for the western Torres Strait subregion and $-103\pm 16$ for the northwest Cape York Peninsula subregion, while not all significantly different, provide more confidence and more locally-relevant values than the

![Figure 1 Ages for conjoining valves of Arca ventricosa from Mer obtained in Runs 279, 317 and 319.](image)
value of +50±47 that has been adopted in recent years (e.g. Reimer and Reimer 2009; Ulm 2006). This larger
dataset obtained with a consistent sampling strategy and calculation to the same chemistry blank indicate that the
apparent differences in marine reservoir activity between eastern and western Torres Strait documented in the
original progress report for AINGRA06181 are not evident. These values are more negative than those obtained for
the Solomons and other island groups to the east of Torres Strait under the influence of the Eastern Australian
Current (Petchey 2009). These new data suggest general uniformity in the magnitude of ΔR across Torres Strait
with more enriched values in the Gulf of Carpentaria. The enriched ΔR values documented here are associated
with the shallow waters of Torres Strait and the Gulf of Carpentaria where there are high rates of atmospheric-
ocean surface ^14C exchange and less mixing with older subsurface waters (cf. Petchey 2009; Ulm et al. 2009).
Such ^14C enrichment of ocean waters may occur in shallow lagoon environments subject to active wave and wind
action (Forman and Polyak 1997). Ongoing consideration of this issue will focus on patterns of ocean currents and
localised upwelling across Torres Strait.

Application of these new ΔR values to calibration of radiocarbon ages obtained on marine samples from Torres
Strait and western Cape York Peninsula result in calendar ages approximately 100 to 150 years older than
calendar ages obtained using the previous recommended value. This work will enhance the value of results
obtained through other AINSE grants in the Torres Strait region (e.g. AINGRA04038, 02/031, 02/032) by providing
more secure characterisation of local marine reservoir conditions for calibration. For example, more precise
calibration of results obtained on archaeological marine samples will help elucidate the chronology of island
occupation and major changes in lifeways, such as the origins of village life.

Results of this study have direct benefit several recently submitted and ongoing research higher degree projects:
Joe Crouch (The Archaeology of Small Islands Around Badu and Mua) (PhD); Jeremy Ash (The Archaeology of
Post-Contact on Mua) (PhD); Duncan Wright (The Emergence of Villages on the Island of Mabuyag) (PhD); and
Robert Skelly (Ritual Resource Management at Loey Ngurtai, Western Torres Strait) (MA Qual.).

Ongoing work will include more detailed consideration of the potential impact of the dietary habits of each sampled
taxa and environmental factors, such as upwelling, terrestrial run-off, circulatory patterns, and the ‘lagoon effect’ on
the observed patterns. Until this wider consideration of the values is completed, the ΔR values reported above
should be used with caution and acknowledgement that they are subject to ongoing review and revision.

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Anderson, A. T.F.G. Higham and R. Wallace 2001 The radiocarbon chronology of the Norfolk Island archaeological

Culleton, B.J., D.J. Kennett, B.L. Ingram, J.M. Erlandson and J.R. Southon 2006 Intrashell radiocarbon variability in


Forman, S.L. and L. Polyak 1997 Radiocarbon content of pre-bomb marine mollusks and variations in the ^14C


40:975-984.

Taylor, J. van der Plicht and C.E. Weyhenmeyer 2004 MARINE04 marine radiocarbon age calibration, 0-26 cal kyr

19th century whales and molluscs from the North Atlantic. Quaternary Science Reviews 25:3228-3245.

Final AMS summary results and sample details are presented in Appendix A. Pooled ΔR values, estimated errors and T-test results for various combinations of the 25 ΔR values available for the Torres Strait region are presented in Appendix B.
Appendix A. Summary final results of AMS dating for AINGRA06181 (Runs 279 & 317) and AINGRA08063 (Run 319). Note that these values differ from those previously reported for AINGRA06181 (Run 279) as the data from Runs 279, 317 and 319 have been recalculated using a common chemistry blank that was used in the processing of data from Run 319. This blank supersedes the blank that was used in Run 279 and is only marginally different from the blank used in Run 317. The new calculations lead to a slight increase in pMC values for Run 279 (i.e. older radiocarbon ages) compared with the originally released data.

| Location                  | Run     | Lab. No. | Species                | Diet# | Weight (g) | Age (yr A.D.) | Model Age | d13C (‰) | % Modern | 14C Age~ (yr BP) | 1σ | 1σ | 14C yr | 1σ | ΔR  
|---------------------------|---------|----------|------------------------|-------|------------|--------------|-----------|-----------|-----------|-----------------|----|----|--------|----|------
| **Western Torres Strait** |         |          |                        |       |            |              |           |           |           |                 |    |    |        |    |      
| Albany Passage            | 317     | OZJ-248/B| Antigona lamellaris     | SF    | 2.7796     | 1907         | 448.8      | 23        | 1.1       | 0.1             | 95.38 | 0.33 | 380    | 30 | -68.8 | 30  
| Albany Passage            | 317     | OZJ-251/B| Placamen calophylla     | SF    | 2.3277     | 1907         | 448.8      | 23        | 1         | 0.1             | 94.59 | 0.42 | 445    | 40 | -3.8  | 40  
| Albany Passage            | 319     | OZL-267  | Minivola pyxidata       | SF    | 0.4411     | 1907         | 448.8      | 23        | 1.4       | 0.1             | 95.64 | 0.36 | 360    | 30 | -88.8 | 30  
| Ngiaigu                   | 279     | OZJ-249  | Nerita undata           | H/O   | 0.7927     | 1923         | 450.2      | 23        | 1.8       | 0.1             | 94.86 | 0.35 | 425    | 30 | -25.2 | 30  
| Ngiaigu                   | 319     | OZL-268  | Nerita undata           | H/O   | 0.7762     | 1923         | 450.2      | 23        | 3.2       | 0.2             | 96.01 | 0.31 | 325    | 30 | -125.2| 30  
| Great Woody Island        | 317     | OZJ-250/B| Gafrawium pectinatum    | SF    | 3.8162     | 1928         | 452.8      | 23        | 1.5       | 0.2             | 95    | 0.31 | 410    | 30 | -42.8 | 30  
| **Eastern Torres Strait** |         |          |                        |       |            |              |           |           |           |                 |    |    |        |    |      
| Mer                       | 317     | OZJ-243/B| Trochus niloticus       | AG    | 61.957     | 1907         | 448.8      | 23        | 3.5       | 0.1             | 95.15 | 0.39 | 400    | 35 | -48.8 | 35  
| Mer                       | 317     | OZJ-244/B| Melo amphora            | C     | 74.19      | 1907         | 448.8      | 23        | 1.9       | 0.1             | 94.31 | 0.34 | 470    | 30 | 21.2  | 30  
| Mer                       | 279     | OZJ-242  | Nerita undata           | H/O   | 3.7851     | 1907         | 448.8      | 23        | 2.6       | 0.1             | 95.44 | 0.35 | 375    | 30 | -73.8 | 30  
| Mer                       | 317     | OZJ-245/B| Arca ventricosa         | SF    | 11.194     | 1907         | 448.8      | 23        | 2.2       | 0.1             | 94.59 | 0.49 | 445    | 45 | -3.8  | 45  
| Mer                       | 317     | OZJ-246/B| Anadara antiquata       | SF    | 29.272     | 1907         | 448.8      | 23        | 1.5       | 0.1             | 93.82 | 0.36 | 510    | 35 | 61.2  | 35  
| Mer                       | 317     | OZJ-247/B| Paphies striata         | SF    | 1.9673     | 1907         | 448.8      | 23        | 0.9       | 0.1             | 94.21 | 0.34 | 480    | 30 | 31.2  | 30  
| Mer                       | 319     | OZL-273  | Paphies striata         | SF    | 1.1489     | 1907         | 448.8      | 23        | 0.9       | 0.1             | 95.38 | 0.33 | 380    | 30 | -68.8 | 30  
| Mer                       | 319     | OZL-274  | Gafrawium pectinatum    | SF    | 2.59       | 1907         | 448.8      | 23        | 2.4       | 0.1             | 95.52 | 0.31 | 370    | 30 | -78.8 | 30  
| Mer                       | 319     | OZL-275  | Arca ventricosa         | SF    | 10.953     | 1907         | 448.8      | 23        | 2.1       | 0.1             | 95.7  | 0.29 | 355    | 25 | -93.8 | 25  
| Mer                       | 319     | OZL-276  | Anadara antiquata       | SF    | 17.394     | 1907         | 448.8      | 23        | 1.2       | 0.1             | 95.5  | 0.36 | 370    | 30 | -78.8 | 30  
| **Gulf of Carpentaria**   |         |          |                        |       |            |              |           |           |           |                 |    |    |        |    |      
| SW of Mapoon              | 319     | OZL-269  | Dosinia histrio        | SF    | 1.1292     | 1903         | 451        | 23        | -0.3      | 0.1             | 95.77 | 0.34 | 345    | 30 | -106  | 30  
| SW of Mapoon              | 319     | OZL-270  | Paphies striata        | SF    | 1.4392     | 1903         | 451        | 23        | -0.5      | 0.2             | 95.69 | 0.4  | 355    | 35 | -96   | 35  
| SW of Mapoon              | 319     | OZL-271  | Antigona lamellaris    | SF    | 2.4632     | 1903         | 451        | 23        | 0.9       | 0.1             | 95.88 | 0.32 | 340    | 30 | -111  | 30  
| SW of Mapoon              | 319     | OZL-272  | Cardita crassicosta    | SF    | 13.448     | 1903         | 451        | 23        | 1.9       | 0.1             | 95.69 | 0.31 | 355    | 30 | -96   | 30  

Previous Values (Gillespie 1977; Rhodes et al. 1980)
<table>
<thead>
<tr>
<th>Location</th>
<th>Run</th>
<th>Lab. No.</th>
<th>Species</th>
<th>Diet#</th>
<th>Weight (g)</th>
<th>Age (yr AD)</th>
<th>Model Age</th>
<th>d13C (‰)</th>
<th>% Modern</th>
<th>14C Age~</th>
<th>1σ yr BP</th>
<th>1σ yr BP</th>
<th>1σ 14C yr</th>
<th>1σ 14C yr</th>
<th>∆R 1σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torres Strait</td>
<td>SUA-354/1</td>
<td>Mactra (Mactra) abbreviata</td>
<td>SF</td>
<td>1875±3</td>
<td>475.2*</td>
<td>23</td>
<td>553</td>
<td>68</td>
<td>77.8</td>
<td>68</td>
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<tr>
<td>Torres Strait</td>
<td>SUA-354/2</td>
<td>Pinna bicolor</td>
<td>SF</td>
<td>1875±3</td>
<td>475.2*</td>
<td>23</td>
<td>536</td>
<td>85</td>
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<td>SUA-357</td>
<td>Pinctada margaritifera</td>
<td>SF</td>
<td>1909</td>
<td>448.6</td>
<td>23</td>
<td>443</td>
<td>84</td>
<td>-5.6</td>
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<td>ANU-1828</td>
<td>Anadara sp.</td>
<td>SF</td>
<td>1903</td>
<td>451</td>
<td>23</td>
<td>576</td>
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<td>-15</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

# H/O-herbivore/omnivore; AG=algae grazer; C=carnivore; SF=suspension feeder.

* Average of 1872-1878 marine model intercepts

~ See Fink et al. (2004). The ages quoted are radiocarbon ages, not calendar ages. No reservoir correction has been made. The ages have been rounded according to Stuiver and Polach (1977). The definition of pMC and conventional Radiocarbon age can also be found in this publication.
Appendix B. Weighted mean $\Delta R$ values, estimated errors and T-test results for various combinations of the 25 $\Delta R$ values available for Torres Strait and Western Cape York Peninsula (NB: shaded cells indicate significantly different results).

<table>
<thead>
<tr>
<th>Description (Rounded Values)*</th>
<th>No.</th>
<th>$\Delta R$ Pooled ($^{14}$C years)</th>
<th>$\chi^2$ Test</th>
<th>$\chi^2/(n-1)$</th>
<th>$\Delta R$ with External Variance ($^{14}$C years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All 25 (inc. 5 previous $\Delta R$ values)</td>
<td>25</td>
<td>-54±7</td>
<td>$T=64.14; \chi^2_{24:0.05}=36.42$</td>
<td>2.76</td>
<td>-54±58</td>
</tr>
<tr>
<td>All 15 SF Only</td>
<td>15</td>
<td>-63±8</td>
<td>$T=36.43; \chi^2_{14:0.05}=23.69$</td>
<td>2.60</td>
<td>-63±44</td>
</tr>
<tr>
<td>All 10 Eastern Torres Strait</td>
<td>10</td>
<td>-40±10</td>
<td>$T=29.03; \chi^2_{9:0.05}=16.92$</td>
<td>3.23</td>
<td>-40±47</td>
</tr>
<tr>
<td>All 7 Eastern Torres Strait SF only</td>
<td>7</td>
<td>-43±12</td>
<td>$T=23.46; \chi^2_{6:0.05}=12.59$</td>
<td>3.91</td>
<td>-43±55</td>
</tr>
<tr>
<td>All 6 Western Torres Strait</td>
<td>6</td>
<td>-63±13</td>
<td>$T=9.31; \chi^2_{5:0.05}=11.07$</td>
<td>1.86</td>
<td>-63±34</td>
</tr>
<tr>
<td>All 4 Western Torres Strait SF only</td>
<td>4</td>
<td>-57±16</td>
<td>$T=3.27; \chi^2_{3:0.05}=7.81$</td>
<td>1.09</td>
<td>-57±24</td>
</tr>
<tr>
<td>All 4 Western Cape York SF only</td>
<td>4</td>
<td>-103±16</td>
<td>$T=0.18; \chi^2_{3:0.05}=7.81$</td>
<td>0.06</td>
<td>-103±16</td>
</tr>
</tbody>
</table>

* SF=suspension feeder.
PUBLICATIONS / REPORTS arising as a result of your work.


PhD STUDENTS

<table>
<thead>
<tr>
<th>Student Name</th>
<th>Thesis Title</th>
<th>Degree</th>
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<tbody>
<tr>
<td>Jeremy Ash</td>
<td>The Archaeology of Post-Contact on Mua</td>
<td>PhD</td>
<td>2010*</td>
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<tr>
<td>Joe Crouch</td>
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<td>Robert Skelly</td>
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<td>MA (Qual.)</td>
<td>2007</td>
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<td>Duncan Wright</td>
<td>The Emergence of Villages on the Island of Mabuyag</td>
<td>PhD</td>
<td>2009 (under examination)</td>
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</table>

* Anticipated conferment date only