

Monthly resolved stable oxygen isotope record in a Palauan sclerosponge *Acanthocheatetes wellsi* for the period of 1977-2001

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Abstract The calcium carbonate in sclerosponge skeletons appears to incorporate stable oxygen isotopes in isotopic equilibrium with seawater, thus faithfully archiving the oxygen isotopic composition of seawater over time at a given site. Here, a high-resolution (0.1 mm) $\delta^{18}\text{O}$ record for the outer 33 mm of an *Acanthocheatetes wellsi* sclerosponge collected in 2001 from Palau (7°N, 134°W) in the northwestern region of the Western Pacific Warm Pool (WPWP) is presented. In this region, seawater $\delta^{18}\text{O}$ is driven primarily by salinity. Radiocarbon and stable isotope analyses reveal that the sclerosponge is 57 years old with an average annual growth rate of 1.355 mm/year. This relatively fast sclerosponge growth rate allows for high-resolution sampling at sub-monthly timescales. In addition, distinct horizontal skeletal features appear to be annual. The detrended sclerosponge $\delta^{18}\text{O}$ record is inversely correlated with the Southern Oscillation Index (SOI). Additional analyses reveal that this interannual variation in sclerosponge $\delta^{18}\text{O}$ is due primarily to the WPWP becoming more saline (fresher) during El Niños (La Niñas). This is consistent with current models and available instrumental data for the WPWP. These results show that sclerosponge $\delta^{18}\text{O}$ records may be a valuable tool for reconstructing paleo-salinity (seawater paleo- $\delta^{18}\text{O}$) variability on interannual timescales. Next, *in situ* calibration studies of sclerosponge $\delta^{18}\text{O}$ versus $\delta^{18}\text{O}_{\text{sw}}$ and salinity are needed to quantitatively interpret sclerosponge $\delta^{18}\text{O}$ records. This paper presents the first paleoceanographic record for the northwestern equatorial Pacific quadrant of the WPWP.

Keywords: sclerosponge, $\delta^{18}\text{O}$, $\Delta^{14}\text{C}$, Southern Oscillation Index, Western Pacific Warm Pool, salinity

Introduction

Predictions of future climate change depend on a firm understanding of the long-term natural variability in the Earth's climate. Proxy records are the only means for reconstructing past climate and ocean conditions and understanding climate change beyond the limits of instrumental records. Instrumental records of the stable oxygen isotopic composition of seawater [$\delta^{18}\text{O}_{\text{sw}} = {}^{18}\text{O}:{}^{16}\text{O}$ relative to Vienna-Standard Mean Ocean Water (SMOW)] and seawater salinity only go back ~30 years and there is very limited spatial and temporal resolution in these measurements. Instrumental records of tropical Pacific sea surface temperature (SST) extending back prior to 1940 are also limited. Multi-decadal to multi-century-long proxy records from many locations within the oceans provides the only means to study the spatial and temporal variation in pre-instrumental oceanographic conditions. Sclerosponges are found throughout the tropics from the surface up to 500 m depth (Swart et al. 1998) and appear to precipitate oxygen in their carbonate skeleton in isotopic equilibrium with seawater without any evidence of strong metabolic effects (Moore et al. 2000). Thus, sclerosponges appear to be recorders of seawater $\delta^{18}\text{O}_{\text{sw}}$ and could provide proxy records of $\delta^{18}\text{O}_{\text{sw}}$ over the past couple of centuries. Sclerosponges present distinct advantages over coral isotope records: they are not light limited and appear to have no metabolic fractionation of their $\delta^{18}\text{O}$ values. Thus, they present a unique opportunity to reconstruct $\delta^{18}\text{O}_{\text{sw}}$ over depth ranges of up to 500 m.

Sclerosponges are slow growing organisms that deposit a calcium carbonate skeleton at a rate of approximately 0.01 – 1.34 mm / year and can grow for up to 1000 years (Willenz and Hartman 1985, 1999; Benavides and Druffel 1986; Böhm et al. 1996; Reitner and Gautret 1996; Wörheide et al. 1997; Swart et al. 1998; Hughes and Thayer 2001; Swart et al. 2002; Fallon et al. 2003). Published growth rates

for *Acanthocheatetes wellsi*, *Astrosclera willeyana*, and *Ceratoporella nicholsoni* are 0.05-1.4, 0.35, and 0.1-0.4 mm/year, respectively. In *A. wellsi*, the calcareous basal skeleton is high-Mg calcite with a density of 1 g/cm³ (Grottoli unpublished) and does not incorporate its siliceous spicules into the skeleton (Hartman 1983). As the *A. wellsi* organism increases in size, portions of the calices below the living tissue are separated off by a series of horizontal skeletal partitions with little to no secondary infilling of the calices (Hartman 1983). Thus, *A. wellsi* is suitable for paleoceanographic reconstruction because the isotopic signal is not averaged or smeared over time due to infilling, and the growth axis can be followed using the horizontal and vertical skeletal features as guides.

Skeletal $\delta^{18}\text{O}$ in marine organisms is affected by temperature-induced fractionation and seawater salinity (Epstein et al. 1953). As temperature increases, the precipitated skeletal $\delta^{18}\text{O}$ decreases (Kim and O'Neil 1997). As salinity increases, the $\delta^{18}\text{O}$ increases. Sclerosponge $\delta^{18}\text{O}$ is proportional to $\delta^{18}\text{O}_{\text{sw}}$ (Moore et al. 2000). In Palau where SST is relatively constant and a three-year calibration study suggests that $\delta^{18}\text{O}_{\text{sw}}$ is directly proportional to salinity (Morimoto et al. 2002), sclerosponge $\delta^{18}\text{O}$ should be proportional to $\delta^{18}\text{O}_{\text{sw}}$ (salinity).

Sclerosponge proxy records from the Western Pacific Warm Pool (WPWP) have begun to be used to reconstruct the natural variability in salinity and SST in the region. The WPWP plays a large role in the global hydrological cycle and is thought to have a significant effect on the distribution of heat between the tropics and extra-tropics on ENSO-to-decadal timescales (El Niño Southern Oscillation) (Hazeleger et al. 2001). This is supported by model evidence that the size and mean mixed-layer salinity and SST of the warm pool varies on seasonal-to-decadal timescales in response to the meridional migration of the inter-tropical convergence zone (ITCZ) and ENSO (e.g. Picaut et al. 1996; Cronin and McPhaden 1997). However, these models are limited by the paucity of reliable, high-resolution *in situ* instrumental measurements. Thus, very little is known about the natural interannual-to-interdecadal timescale variability of salinity and SST in the WPWP. The Republic of Palau, located in the northwestern quadrant of the WPWP, is an area for which very little long-term paleoclimatic or paleoceanographic data exists (Fig. 1). High-resolution *in situ* sea surface temperature records extend back to the early-1980s and no high-resolution long-term records of either salinity or $\delta^{18}\text{O}_{\text{sw}}$ exist for this region of the WPWP. This paper presents a monthly resolved, 25 year-long *Acanthocheatetes*

wellsii sclerosponge $\delta^{18}\text{O}$ record from a Palau for the period of 1977-2001. The results of the study show that the $\delta^{18}\text{O}$ signature in *A. wellsi* tracked ENSO variability over the past three decades and strongly suggest that it is a seawater salinity proxy.

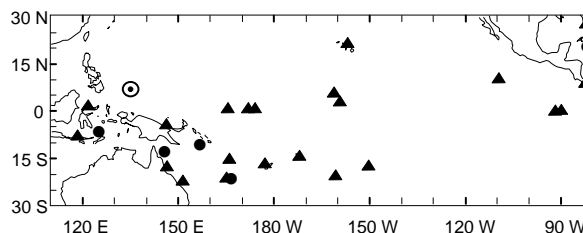


Fig. 1. Location of collection site (dotted circle (⊙) = Palau, 7N, 134 E) and other published sclerosponge and coral proxy records. Black circles (●) = locations of published sclerosponge isotope records > 30 years: *Ceratoporella nicholsoni* in Jamaica (Druffel, Benavides 1986; Böhm et al 1996) and the Bahamas (Lazareth et al. 2000; Swart et al 2002), *Acanthocheatetes wellsi* in New Caledonia (Böhm et al 1996) and the Great Barrier Reef (Wörheide et al 1997), and *Astrosclera willeyana* at the GBR (Wörheide et al 1997), Solomon Islands and Indonesian Seaway (Moore et al 2000). Black triangles (▲) = locations of the published coral isotope records >30 years listed and referenced at www.ncdc.noaa.gov/paleo as of December 2004.

Method

Study site: Short Drop Off, Palau

The Republic of Palau is within the WPWP at ~7°N, 135°E (Fig. 1). Short Drop Off, Palau (7°16.4'N, 134°31.4'E) is a reef wall located 2 km offshore of the windward side of the island chain. Short Drop Off experiences good open ocean flushing with a dominant current that travels the length of the wall, is unaffected by runoff from land, and is not influenced by temperature and salinity dynamics of caves or lagoons as many other sclerosponges sites are. Advanced Very High Resolution Radiometers (AVHRR) nighttime Pathfinder satellite data from 1985 – 2001 (<http://orbit-net.nesdis.noaa.gov>) shows no long-term trend in SST, and the Integrated Global Ocean Services System Products Bulletin's Global (IGOSS) SST data from 1981-2005 by Reynolds et al. (2002) (http://iridl.ldeo.columbia.edu/SOURCES/IGOSS/nmc/Reyn_SmithOIv2/monthly/.sst) shows a slight warming trend in SST. The average annual range in SST at Palau is about 2.5°C, with cooler SST in winter and mid-summer and warmer SST of ~30°C in the spring and fall (Fig. 2). *In situ* temperature measurements at Short Drop Off from July 2001-

2003 show a similar seasonal pattern and range of SST to the IGOSS data indicating that the IGOSS data are a good measure of local SST variability (Fig. 2). Salinity in the region ranges from 32.4-35.4 ppt (Schmidt et al. 1999; Morimoto et al. 2002) and $\delta^{18}\text{O}_{\text{sw}}$ can range from -0.5 to 0.8‰ (rel to SMOW) (Schmidt et al. 1999; Morimoto et al. 2002). But long-term variability in salinity and $\delta^{18}\text{O}_{\text{sw}}$ are not very well known because available instrumental data is limited to a single cruise (Schmidt et al. 1990) and to three years of *in situ* measurements from 1998 to 2000 (Morimoto et al. 2002). *Acanthocheatetes wellsi* sclerosponges are found in abundance within 1 m of large crack/crevice openings which are well flushed, at depths ranging from 5 –20 m, and easily located within the minimum mixed-layer depth of ~29 m year-round (Patrick Collins, unpublished data; Lukas and Lindstrom 1991).

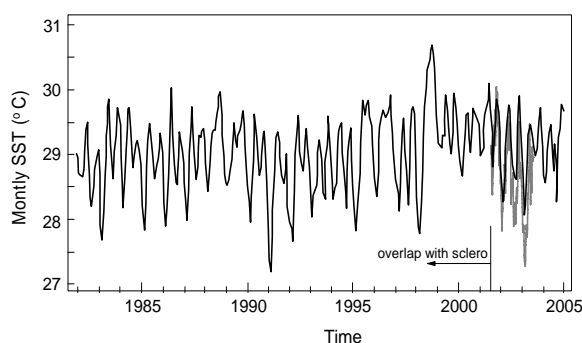


Fig. 2. Sea surface temperature (SST) near Palau centered at 7°N, 134°E from the Integrated Global Ocean Services System Products Bulletin's Global SST data by Reynolds et al. (2002) available at http://iridl.ldeo.columbia.edu/SOURCES/IGOSS/nmc/Reyn_SmithOlv2/monthly/.sst (Black). *In situ* temperature from a submersible logger at Short Drop Off from July 2001- July 2003 (Gray).

Sclerosponge specimen: *Acanthocheatetes wellsi*

In July 2001, a 77 mm tall *Acanthocheatetes wellsi* sclerosponge specimen was collected at 17 m depth at Short Drop Off, Palau, and transported back to the University of Pennsylvania for isotopic analysis. The specimen was cut into a 15 mm thick slab along its major axis of growth, cleaned with pressurized water, sonicated in Milli-Q filtered water, and then dried for 5 days at 60°C (Fig. 3). The sclerosponge slab was sampled by milling the skeleton along the maximum axis of growth at 0.1 mm increments for the outermost 33 mm of the sclerosponge using a high-precision, computer-driven Merchantek microdrill attached to an x, y, z controlled stage. While others have successfully obtained sclerosponge samples at 0.03 – 0.5 mm

resolution (Hughes and Thayer 2001; Swart et al. 2002), a sampling resolution of 0.1 mm increments seems to improve annual and longer timescale pattern recognition (Fallon et al. 1998). A total of 180-300 μg of material was obtained for each sample at this resolution. The drilling path was restricted to a 7 mm wide by 1 mm deep trough. A 7 mm wide trough was necessary to ensure that at least 100 μg was extracted for each sample. Drilling followed the curvature of the horizontal skeletal growth bands thus minimizing any temporal smoothing that can occur from taking a wide sample. Comparison of sample material extracted from the 2.5 mm on the left-hand side of the drill path with material extracted from the 2.5 mm on the right-hand side of the drill path revealed that the difference was less than analytical error for $\delta^{18}\text{O}$ values ($n=21$ pairs, mean difference between pairs = $0.037\text{‰} \pm 0.05$). Thus, the isotopic signal across the entire 7 mm sample is the same, and any temporal smearing is below analytical detection.

Each skeletal sample was analyzed for $\delta^{18}\text{O}$ by acidifying a 100 μg subsample in 100% orthophosphoric acid and measuring the resulting CO_2 with a Finnigan MAT 252 mass spectrometer fitted with an automated carbonate Kiel device and reported as the permil deviation relative to V-PDB (Vienna-Peedee Belemnite Limestone Standard). 10% of samples were run in duplicate to ensure reproducibility. The precision of replicate analyses was $\leq 0.08\text{‰}$ for $\delta^{18}\text{O}$.

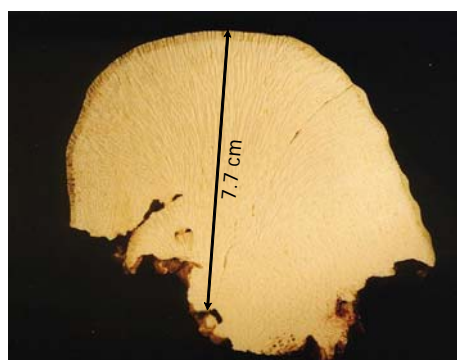


Fig. 3. Cross-section of *Acanthocheatetes wellsi* specimen from Palau prior to drilling. Line indicates drilling path. Tissue thickness is approximately 2 mm deep.

Following the high-resolution sampling, 10 mg samples were drilled out at 10 mm increments along the entire 77 mm specimen for radiocarbon analysis to help establish the chronology. Additional samples were taken every 2 mm between 60 and 70 mm to further refine the chronology. Approximately 7 mg of each sclerosponge sample was acidified under

vacuum at 90°C with orthophosphoric acid in individual containers (Guilderson et al. 1998). The resulting CO₂ was cryogenically purified and reduced to graphite under hydrogen gas using an iron catalyst to produce a 0.8 mg graphite target (Vogel et al. 1987). The radiocarbon content of the graphite was measured using accelerator mass spectrometry (AMS) techniques and reported as Δ¹⁴C (the per mil deviation of ¹⁴C/¹²C of the sample relative to that of 95% Oxalic Acid-1 standard) (Stuiver and Polach 1977) and include a δ¹³C and blank correction. All of the AMS measurements were made at CAMS (Center for Accelerator Mass Spectrometry at Lawrence Livermore National Laboratories) with a precision of ± 4.0‰ or less (1 standard deviation). ¹⁴C is produced naturally in the stratosphere and was also produced as a result of thermonuclear weapons explosions in the atmosphere in the 1950s and early 1960s. The base of the Δ¹⁴C-bomb is clearly identifiable by 1955 in coral carbonate records (i.e. Druffel and Linick 1978; Druffel 1981) and can be used to help set the chronology (e.g., see Fig. 4).

The sclerosponge δ¹⁸O chronology was derived from the radiocarbon record and the Timer program from the free Arand software package (courtesy of Philip Howell, Brown University, <ftp://pixie.geo.brown.edu/pub>) was applied to the δ¹⁸O record to produce a monthly δ¹⁸O record through interpolation which was then analyzed using time-series analysis techniques. The spectral energy was evaluated and cross-spectral and correlation analyses were performed between δ¹⁸O and the Southern Oscillation Index (SOI) (<http://www.bom.gov.au/climate/current/soi2.shtml>) using Arand software. The results presented here are for the outermost 33 mm of the sclerosponge δ¹⁸O. A complete analysis of the entire 77 mm δ¹⁸O and δ¹³C record and of the Sr/Ca values is still underway and will be published elsewhere.

Results

Sclerosponge chronology

Radiocarbon (Δ¹⁴C) measurements show that the onset of the Δ¹⁴C-bomb curve, which occurred in 1955, starts at 63 mm from the surface (Fig. 4). Assuming a linear growth rate between 1955 and the collection date, the mean annual growth rate was calculated to be 1.355 mm/year. At a 100 μm resolution, that is equivalent to almost 14 samples per year (sub-monthly resolution). Using the 1.355 mm/year growth rate, the date at the base of the high resolution 33 mm long δ¹⁸O record was calculated to be 1977. The detrended δ¹⁸O record was then compared to the SOI. Without any chronological adjustments, the detrended δ¹⁸O matched up very

well with the SOI for the period of 1977-2001 and reconfirmed that the record started in 1977. The Timer program was then applied to the δ¹⁸O record to produce a monthly δ¹⁸O record (Fig. 6). Since this specimen grows an average of 1.355 mm yearly yielding ~14 samples per year, the interpolated monthly δ¹⁸O record (12 samples per year) is conservative and therefore acceptable.

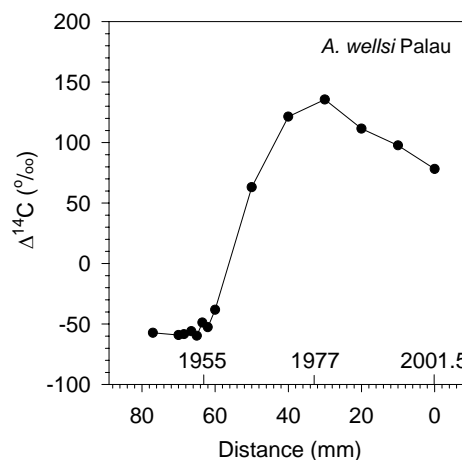


Fig. 4. Palauan *Acanthocheatetes wellsi* sclerosponge radiocarbon values (Δ¹⁴C) measured every centimeter along the major axis of growth. The initial date (0 mm) of 2001.5 is the mean date for the entire time period covered by the first Δ¹⁴C sample. Base of bomb curve = 63 mm (1955). Analytical precision of each Δ¹⁴C measurement is ± 4‰ (1 standard deviation) or less.

Sclerosponge δ¹⁸O

Mean sclerosponge δ¹⁸O values decreased by ~ 0.22‰ from 33 mm to the top of the core (1977-2001) with most of the decrease occurring in the last 10 mm of the record, which is equivalent to the period spanning 1994 – 2001 (Fig. 5). This decrease in δ¹⁸O indicates that seawater in Palau was warming and/or freshening over that time. Large deviations from the long-term mean were also observed on interannual timescales. Spectral analyses of the detrended monthly sclerosponge δ¹⁸O record revealed an annual and a 3-6 year centered frequency peak. The monthly SOI for 1977-2001 also exhibited a spectral peak centered about the 2-6 year frequency. Detrended monthly sclerosponge δ¹⁸O was inversely correlated with the monthly SOI (p < 0.0001, r² = 0.24), and the two records demonstrate coherence at the 4.6 year frequency at the 95% confidence level (Cross-spectral analysis, Arand Software). This was the only frequency at which significant coherence was found between the sclerosponge δ¹⁸O and SOI

records. The variation that is explained by the correlation between sclerosponge $\delta^{18}\text{O}$ and SOI improves by 63% when the detrended monthly $\delta^{18}\text{O}$ and SOI values are smoothed with a 3-month and 5-month running mean, respectively ($p < 0.0001$, $r^2 = 0.38$) (Fig. 6, 7). Overall, during strong warm phases of ENSO (El Niño), the SOI is strongly negative and sclerosponge $\delta^{18}\text{O}$ is strongly positive whereas during strong cool phases of ENSO (La Niña) the opposite occurs. No clear correlation was observed between the sclerosponge $\delta^{18}\text{O}$ values (original or detrended) and SST (compare Figs. 2 to Figs. 5 and 6).

Discussion

Sclerosponge chronology

The bomb- $\Delta^{14}\text{C}$ curve is clearly visible in the *Acanthocheatetes wellsi* sclerosponge specimen and effectively identifies ~1955 on the growth axis. The calculated growth rate of 1.355 mm/year in this *A. wellsi* specimen is quite high compared to other published growth rates for *A. wellsi* that range from 0.05 – 0.45 mm/year in Australia and New Caledonia (Böhm et al. 1996; Reitner and Gautret 1996; Wörheide et al. 1997) and similar to the 1.5 mm/y in Vanuatu (Fallon et al. 2003). However, this growth rate is almost identical to the 1.34 mm/year growth rate measured in a 20 mm tall (15 year old) *A. wellsi* sclerosponge in Palau (Hughes and Thayer 2001). Consistency between the growth rate of a 20 mm tall and the 77 mm tall *A. wellsi* sclerosponge in this study suggests that growth rate might be constant with age in this sclerosponge species at this location.

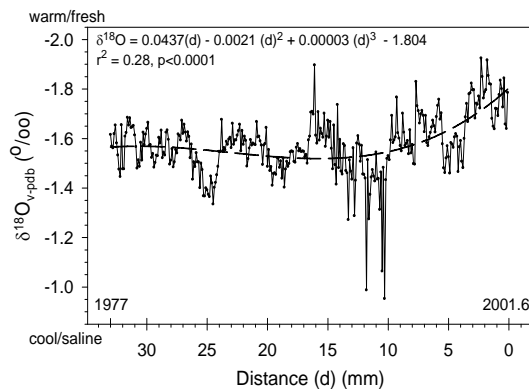


Fig. 5. $\delta^{18}\text{O}$ measured at 0.1 mm increments for the outermost 33 mm of the *Acanthocheatetes wellsi* sclerosponge specimen. Beginning of the record is set by the collection date of July 2001. The base of the record is set by the $\Delta^{14}\text{C}$ record. Equation describes the best fit line (gray dashed).

Visible horizontal skeletal structures are separated by

1.40 mm \pm 0.36 (1 Stdev) (average calculated from measurements of the distance between horizontal structures at 20 randomly selected locations along the growth axis); very close to the estimated 1.355 mm/yr growth rate. These “annual” layers have also been observed in a New Caledonian *A. wellsi* sclerosponge (Fallon et al. 2003). The high and constant growth rate in *A. wellsi* in Palau thus allows for monthly or better sampling resolution using microdrilling techniques for stable isotope analysis. Further research is needed to confirm that the skeletal layers are annual.

Long-term trend and interannual variability in sclerosponge $\delta^{18}\text{O}$

The sclerosponge $\delta^{18}\text{O}$ record shows a long-term trend and interannual variability. Over the course of the 24-year record, sclerosponge $\delta^{18}\text{O}$ decreased by $\sim 0.22\text{‰}$ with a vast majority of the decrease occurring in the last seven years of the record (0.2‰ decrease post-1994) (Fig. 5). If $\delta^{18}\text{O}$ decreases by 0.22‰/°C according to the inorganic temperature slope for water (Kim and O’Neil 1997), then the measured decrease observed in this sclerosponge record corresponds to a $\sim 1^\circ\text{C}$ increase in seawater temperature focused largely between 1994 and 2001. This warming is large compared to the mean global SST increase of 0.3°C from 1976-2000 (Folland and Karl 2001), and compared to SST data for the region that shows a moderate $\sim 0.4^\circ\text{C}$ warming from 1981-2001 (IGOSS data, Fig. 2) or no noticeable warming over the region from 1985-2001 (AVHRR data,

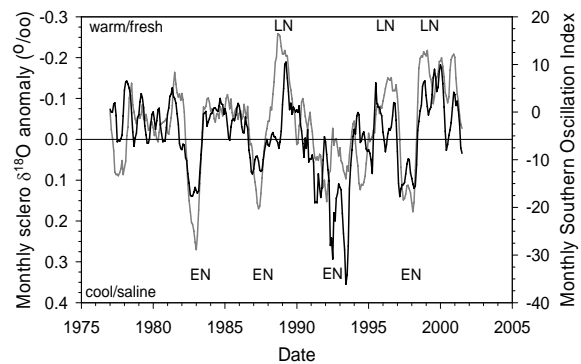
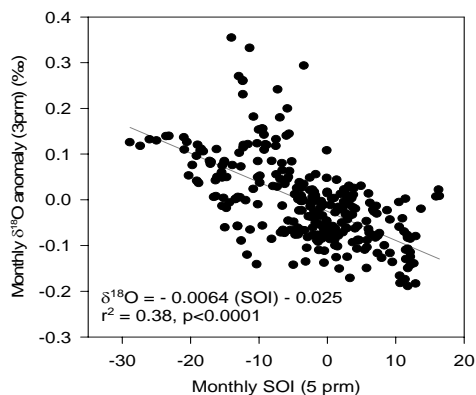


Fig. 6. Monthly sclerosponge $\delta^{18}\text{O}$ anomaly (black) (3-month running mean) is inversely correlated to the monthly Southern Oscillation Index (SOI) (gray) (5-month running mean) (see Fig 7 also). El Niño (EN) and La Niña (LN) events indicated at the bottom and top of the figure, respectively.

Fig. 7. Plot of the monthly sclerosponge $\delta^{18}\text{O}$ anomaly (3-month running mean) versus the



monthly Southern Oscillation Index (SOI) (5-month running mean) shown in Fig. 6. Regression line (gray) is described by the equation shown. All $\delta^{18}\text{O}$ values greater than 0.2 correspond occurred between 1992 and 1994.

<http://orbit-net.nesdis.noaa.gov>). Combined, these instrumental records indicate a small warming in Palau that could account for ~20% of the variability in $\delta^{18}\text{O}$ over the entire record. Comparison of the temperature and sclerosponge $\delta^{18}\text{O}$ records (Figs. 2 & 5) reveals that the two records do not show similar long-term trends. In addition, the mean monsoon convection state over the WPWP and Indian Ocean seems to vary on decadal timescales (Chu and Wang 1997), which could produce increased rainfall (lower seawater $\delta^{18}\text{O}$) at Palau. Overall, the change in sclerosponge $\delta^{18}\text{O}$ is much greater than would be expected from temperature alone supporting the idea that the majority of the long-term $\delta^{18}\text{O}$ change appears to be driven by changes in salinity ($\delta^{18}\text{O}_{\text{sw}}$), possibly connected to a shift in precipitation regime. Additional studies of longer sclerosponge records that include multiple decades of sclerosponge $\delta^{18}\text{O}$ data are currently in progress and will be examined for long-term and decadal timescale variability.

The sclerosponge $\delta^{18}\text{O}$ record also shows a high degree of interannual variability (Fig. 6) while the $\delta^{18}\text{O}$ anomaly shows a strong negative correlation with SOI (Fig. 7). During strong warm phases of ENSO (El Niño), the SOI is strongly negative and sclerosponge $\delta^{18}\text{O}$ is strongly positive, suggesting that the northwestern quadrant of the WPWP is cooler and/or more saline at that time. During strong cool phases of ENSO (La Niña), the opposite occurs. Since SST is known to be relatively constant in the WPWP on interannual timescales (McGregor and Nieuwolt 1998) (Fig. 2), the $\delta^{18}\text{O}$ data again suggest that sclerosponge $\delta^{18}\text{O}$ in Palau is primarily driven by changes in salinity. This is supported by three pieces of evidence. First, recent work by Morimoto (Morimoto et al. 2002) showed that 93% of the variability in $\delta^{18}\text{O}_{\text{sw}}$ in Palau is due to changes in salinity. Second, modeling studies show that

changes in salinity in this region are largely due to large-scale shifts in the amount of monsoon rains associated with ENSO variability on interannual timescales (McGregor and Nieuwolt 1998; Feely et al. 2002). Third, the maximum range in the sclerosponge $\delta^{18}\text{O}$ anomalies is 0.53‰ with the maximum value observed in early 1989 and the minimum in mid-1994 (Fig. 6), which would be equivalent to 2.4°C if the $\delta^{18}\text{O}$ variability were all due to changes in SST. However, comparison with SST data from Fig. 2 shows that the same time periods correspond to only a 1°C range in temperature. Hence, the change in sclerosponge $\delta^{18}\text{O}$ is much greater than would be expected from temperature alone and supports the idea that the majority of the interannual $\delta^{18}\text{O}$ variability appears to be driven by changes in salinity ($\delta^{18}\text{O}_{\text{sw}}$).

Lastly, the lack of any significant correlation between the monthly sclerosponge $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ anomalies ($p < 0.49$, $r^2 = 0.002$) indicates that $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ are independent of each other and that sclerosponge $\delta^{18}\text{O}$ is unaffected by metabolic activity (correlation figure not shown). However, calibration studies of sclerosponge $\delta^{18}\text{O}$ versus $\delta^{18}\text{O}_{\text{sw}}$ needed to quantitatively interpret sclerosponge $\delta^{18}\text{O}$ records have not been conducted for any of the Pacific sclerosponges. Such a calibration study has just been funded and is currently underway in Grottoli's lab.

Overall, sclerosponge-derived proxy records would lend insight into the spatial and temporal variability in the $\delta^{18}\text{O}_{\text{sw}}$, thus extending existing instrumental salinity ($\delta^{18}\text{O}_{\text{sw}}$) data sets by several decades throughout the tropical Pacific Warm Pool and other regions where $\delta^{18}\text{O}_{\text{sw}}$ is predominantly driven by salinity. Ideally, studies from additional sclerosponge specimens are needed to ensure reproducibility of the results. *In situ* calibration studies of sclerosponge $\delta^{18}\text{O}$ versus seawater $\delta^{18}\text{O}_{\text{sw}}$, salinity, and temperature are now needed to quantitatively interpret sclerosponge $\delta^{18}\text{O}$ records for Pacific sclerosponge species.

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