

Extracting growth rates from the nonlaminated coralline sponge *Astrosclera willeyana* using bomb radiocarbon

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Abstract

The isotopic and chemical composition of the skeletons of hermatypic reef building corals have been used for many years to generate proxy time series records of surface oceanic conditions (water temperature and salinity). These types of records have recently been constructed using coralline sponges. Because they are found in a greater range of depths, coralline sponges have the potential to fill in gaps in our understanding of subsurface oceanographic variability. Using coralline sponges together with surface corals, we can obtain a three-dimensional (3D) picture of oceanographic/climate variability. However, coralline sponges have one disadvantage compared to hermatypic reef building coral proxies in that most do not have annual density bands and need to be radiometrically dated for age determination. We have measured radiocarbon in 1 mm increments from *Astrosclera willeyana* sponges collected off the Central and Northern Great Barrier Reef (GBR) and from Truk in the Caroline Islands and compared these radiocarbon profiles to independently dated coral radiocarbon records to examine growth rate variability. Growth rates of the GBR sponges averaged 1.2 ± 0.3 and 1.0 ± 0.3 mm y^{-1} at north and central sites respectively, but the growth rate can vary by a factor of two over the life span of the sponge. The growth rate of the Truk sponge averaged 1.2 ± 0.1 mm y^{-1} . These growth rates are faster than those measured for other *Astrosclera willeyana* sponges ($0.2\text{--}0.7$ mm y^{-1}) (Moore et al. 2000; Wörheide 1998).

Coralline sponges are slow-growing, long-lived organisms, and their calcareous skeletons can provide information on salinity and water temperature variations over their life span. Unlike corals, most coralline sponges do not exhibit any annual variations of density or skeletal structure, making it difficult to relate predicted environmental parameters to specific times. Previous studies have determined growth rates in coralline sponges by staining (Dunstan and Sacco 1982; Rosenheim et al. 2004; Willenz and Hartman 1985, 1999) or radiometric methods, ^{14}C , ^{210}Pb , and $^{230}\text{Th}/^{234}\text{U}$ (Benavides and Druffel 1986; Böhm et al. 2000; Fallon et al. 2003; Moore et al. 2000; Wörheide 1998). The majority of paleo-reconstructions take a single linear extension rate extrapolated to the whole

organism. In this study, we determine the age and growth rate of a sponge by taking advantage of the atmosphere/surface ocean changes in ^{14}C due to nuclear weapons testing in the 1950s and 1960s and comparing our sponge ^{14}C data to known age surface seawater ^{14}C values.

Surface ocean radiocarbon ($\Delta^{14}\text{C}$) is a combination of several processes, including lateral mixing of water masses, upwelling of lower ^{14}C water masses, and air/sea gas exchange of CO_2 that brings higher atmospheric $^{14}\text{CO}_2$ to the surface ocean. Atmospheric nuclear weapons testing in the 1950s and 1960s increased the atmospheric $\Delta^{14}\text{C}$ by $\sim 1000\text{‰}$ (Levin et al. 1985). The isotopic equilibration time between atmosphere and surface seawater is on the order of a decade, suggesting that if all processes are equal (in reality they are not) the surface ocean $\Delta^{14}\text{C}$ should have peaked around 1973 (1962–1963 being the highest atmospheric $\Delta^{14}\text{C}$ in the Northern Hemisphere) (Broecker and Peng 1982). The variations of surface water $\Delta^{14}\text{C}$ over time, the amplitude, and the timing of the bomb peak provide detailed information about the oceanography and air/sea $^{14}\text{CO}_2$ exchange of an area. In general, the bomb curve of surface ocean $\Delta^{14}\text{C}$ has the same general shape in the world's oceans. The surface ocean $\Delta^{14}\text{C}$ began to rise in the late 1950s, peaked in the 1970s, and then began to

Acknowledgments

We would like to thank Gert Wörheide for teaching S.J.F. to sniff out the *Astrosclera* and to John Hooper for access to the Queensland Museum sample archive. Thanks also to Paula Zermeño and Dot Kurdyla for help in the graphite lab. This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract Nr W-7405-Eng-48. Funding for this project was supplied by UC/LLNL LDRD projects 98-ERI-002 and 01-ERI-009 to T.P.G.

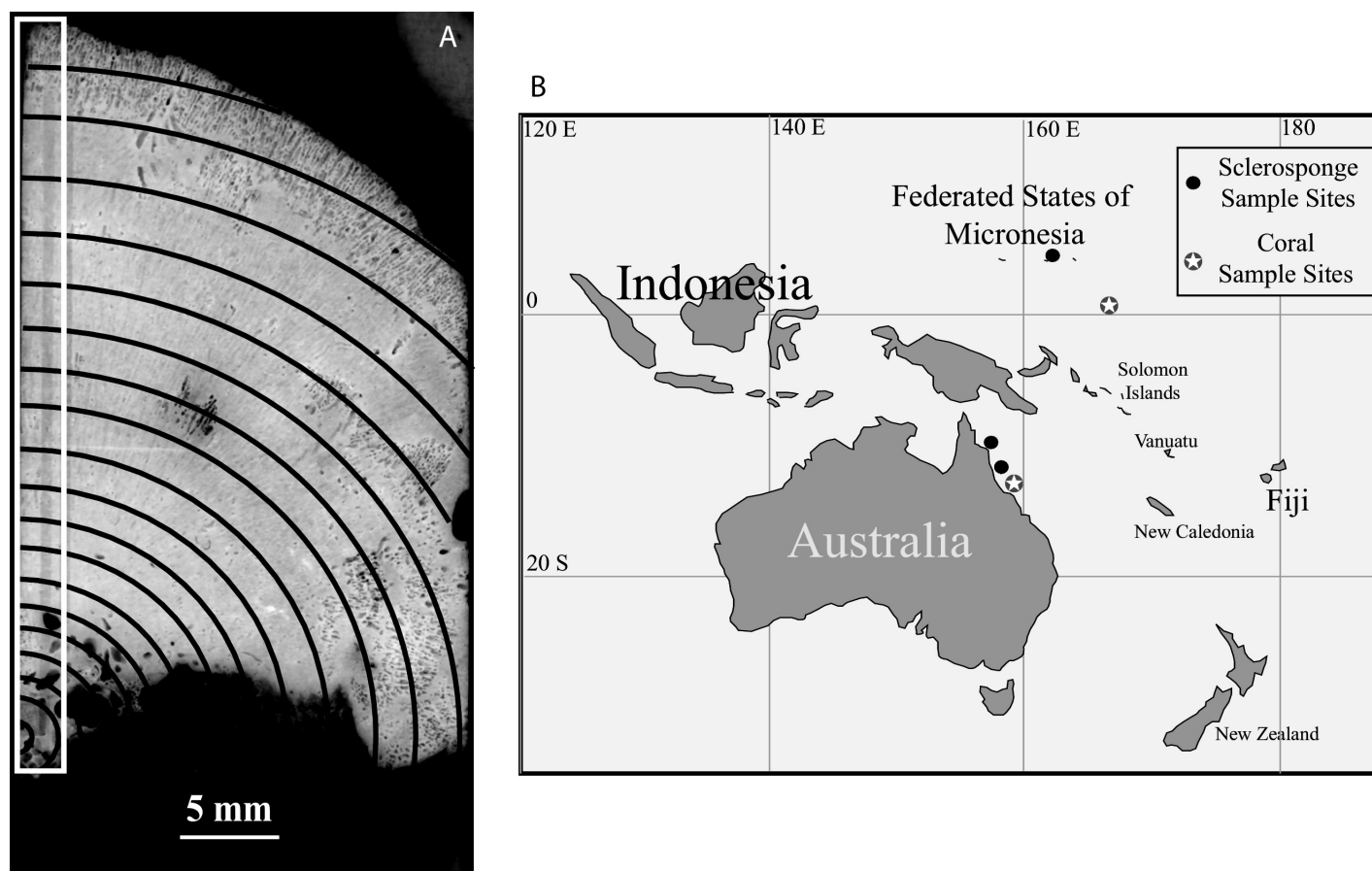


Fig. 1. (A) Image of half of a coralline sponge *Astrosclera willeyana* (Myrmidon Reef sample) slab with idealized concentric growth bands overlaid and $\Delta^{14}\text{C}$ sampling box in white. (B) Map showing the *Astrosclera willeyana* sample locations and coral record locations.

decrease. In areas with similar radiocarbon surface water processes we can take advantage of the bomb curve from a well-dated coral to provide an age model for nonlaminated coralline sponges like *Astrosclera willeyana* (Benavides and Druffel 1986; Böhm et al. 2002). Here we examine and determine the growth rate of the Indo-Pacific coralline sponge *Astrosclera willeyana* using high resolution $\Delta^{14}\text{C}$ measurements compared to precisely dated coral $\Delta^{14}\text{C}$ records. This enables a detailed examination of growth rate variability that is crucial to applying these sponges as environmental proxies.

Materials and procedures

The coralline sponges were cut into 5 mm thick slabs, cleaned in Milli-Q water, and dried at 40°C. Samples were milled sequentially in 1 mm increments (sample dimension 5 mm depth \times 2 mm wide \times 1 mm in time) with every sample analyzed. Sponges were milled down the “center” of the slab (Fig. 1). ^{14}C sample splits (~7 mg) were evacuated, heated, and acidified in individual chambers with orthophosphoric acid at 90°C (Guilderson et al. 1998). The CO_2 was purified, trapped, and converted to graphite using an iron catalyst following a method similar to that described by Vogel et al. (1987). The

graphite targets were analyzed at the Center for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratory. The ^{14}C results are reported as age-corrected $\delta^{14}\text{C}$ (‰) as defined by Stuiver and Polach (1977) and include $\delta^{13}\text{C}$ correction for isotope fractionation and a blank subtraction based on ^{14}C -free calcite. Radiocarbon accuracy and precision is 3.2‰ (1 σ) based on replicate analyses of a homogenous in-house coral standard ($n = 89$). X-ray and visual analysis of these sponges did not reveal any visible annual growth bands similar to hermatypic corals and to the coralline sponge *Acanthochaetetes wellsi* (Fallon et al. 2003). Two samples were collected from the Great Barrier Reef, Ribbon Reef nr 10 at a depth of 21 m and Myrmidon Reef at a depth of 17 m (Table 1, Fig. 1). An additional sample was collected by J. Hooper (Queensland Museum) from Truk in the Caroline Islands at a depth of 25 m (Table 1, Fig. 1).

Assessment

The Myrmidon sponge is the largest at 51.7 mm followed by the Ribbon Reef at 31.9 mm and the Truk sponge at 18.2 mm. The radiocarbon ($\Delta^{14}\text{C}$) results from the three sponges are shown in Fig. 2. The Myrmidon sponge $\Delta^{14}\text{C}$ record displays a

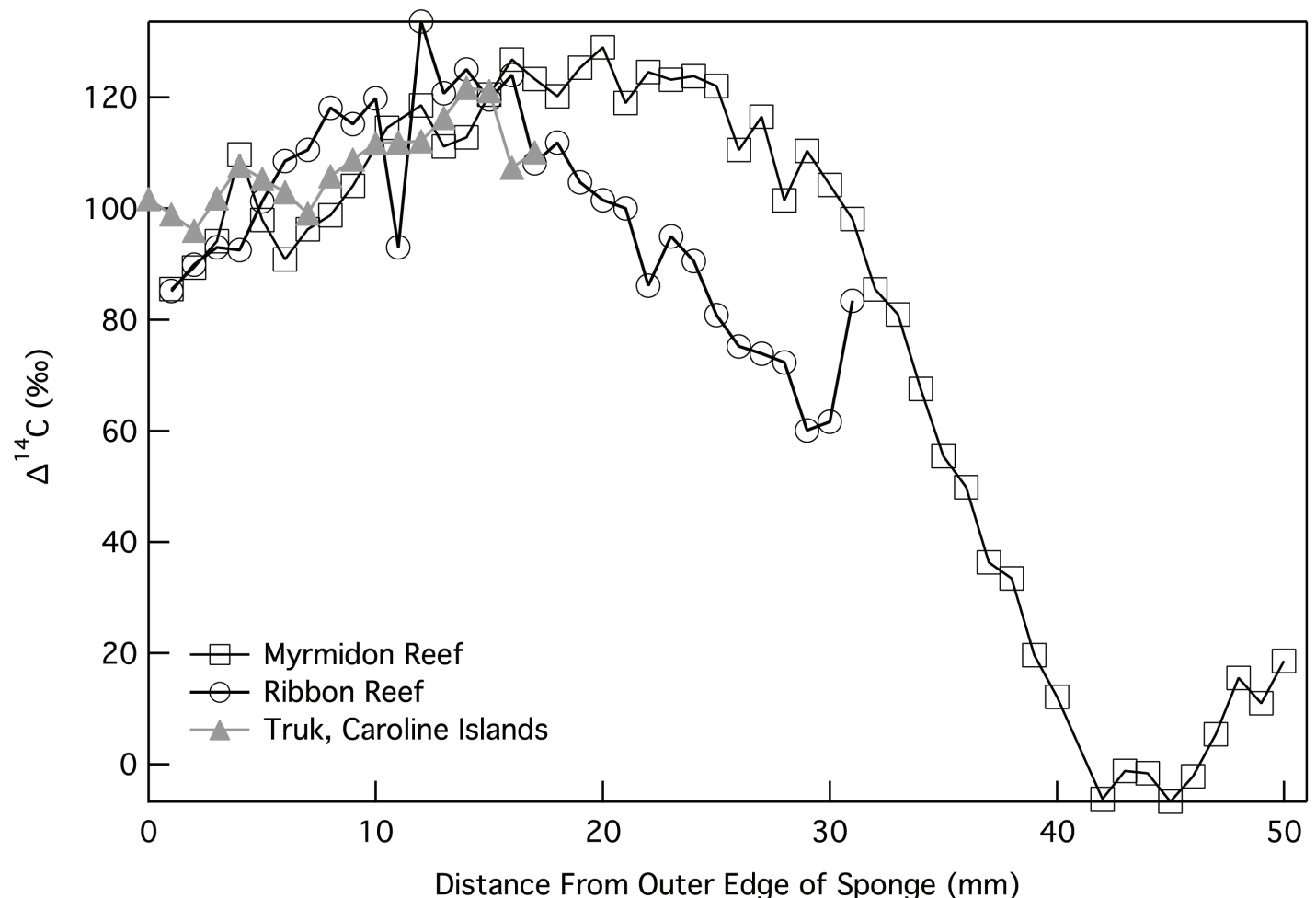
Table 1. Details of Sclerosponge samples

Location	Latitude/ Longitude	Collection depth (m)	Collection date	Sample size (base to top center mm)
Ribbon Reef, GBR	14.40 S/145.40 E	21	8 Aug 1998	31.9
Myrmidon Reef, GBR	18.6 S/147.5 E	17	18 Jan 1999	51.7
Otta Island, Truk, Caroline Islands	7.12 N/151.51 E	25	8 Aug 1994	18.2

rapid rise and peak due to the atmospheric nuclear weapons testing of the 1950s and 1960s but does not extend to the “pre-bomb” period, before 1955 (Fig. 2). The Ribbon Reef sponge $\Delta^{14}\text{C}$ captures only part of the bomb rise whereas the Truk sample doesn’t quite extend to the bomb peak (Fig. 2).

We compared the sponge $\Delta^{14}\text{C}$ -distance data to two coral $\Delta^{14}\text{C}$ records recovered from Heron Island and Abraham Reef, GBR (Druffel and Griffin 1995), to determine the growth rates for the Myrmidon and Ribbon Reef sponges. The shape of a seawater $\Delta^{14}\text{C}$ curve is diagnostic. Overall it depends on hemispheric scale atmosphere ocean exchange of CO_2 coupled with regional oceanographic conditions. Nearby regions should

have very similar $\Delta^{14}\text{C}$ time histories unless an extreme local phenomenon (i.e., upwelling) influences the local seawater ^{14}C content. Therefore, we can use a well-dated seawater ^{14}C record such as coral $\Delta^{14}\text{C}$ records as the value for seawater $\Delta^{14}\text{C}$ at a particular time period. We then visually match specific features in the sponge $\Delta^{14}\text{C}$ record with the coral $\Delta^{14}\text{C}$ record. These “marker points” are used to assign a date to the corresponding sponge $\Delta^{14}\text{C}$ value. Marker points are usually chosen at inflection points (Figs. 3-5). Fig. 3 shows the Myrmidon sponge sample versus time using the labeled marker points compared to the two coral datasets. The $\Delta^{14}\text{C}$ coral data were sampled from discrete annual bands cut on the leading edge

**Fig. 2.** *Astrosclera willeyana* sample $\Delta^{14}\text{C}$ versus distance from the outer edge of the sponge. Sponge $\Delta^{14}\text{C}$ errors are the size of the symbols.

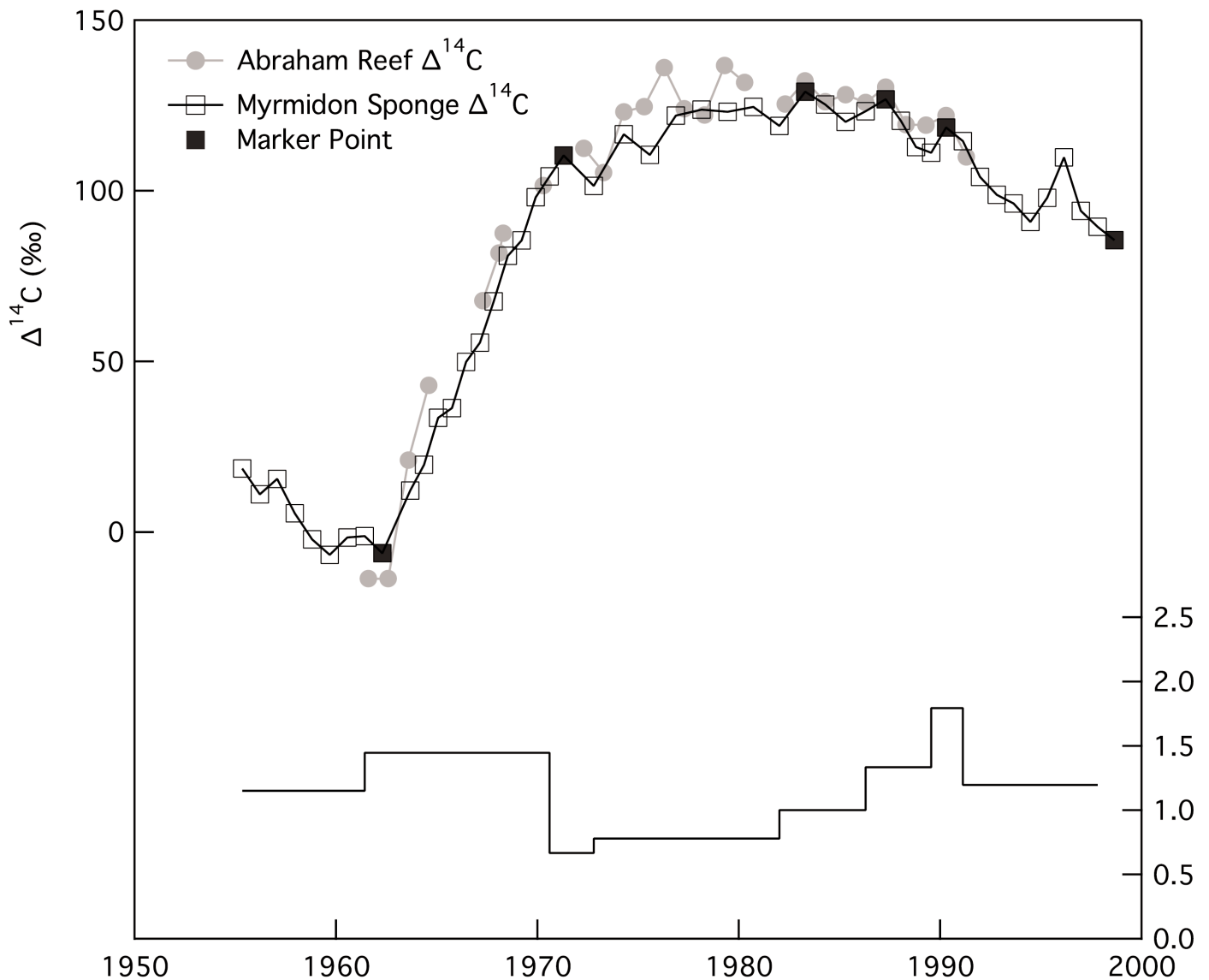


Fig. 3. Upper portion: *Astrosclera willeyana* sample from Myrmidon Reef fit to the Heron Island and Abraham Reef corals (Druffel and Griffin 1995). Lower portion: Growth rate of sponge from fit to GBR corals using marker points. Sponge $\Delta^{14}\text{C}$ errors are the size of the symbols.

of the high-density bands and is accurate to about a year (Druffel and Griffin 1995). Using the sample collection date and the marker points, extension rates for the entire time series and between marker points can be calculated (Fig. 3). The Myrmidon sponge has an average extension rate of $1.2 \pm 0.3 \text{ mm y}^{-1}$ with extension rate values between the marker points ranging from 0.7 to 1.8 mm y^{-1} (Fig. 3). The Ribbon reef sponge has an average extension rate of $1.0 \pm 0.3 \text{ mm y}^{-1}$ with values ranging from 0.7 to 1.5 mm y^{-1} (Fig. 4). These data show that sponge growth rate may vary by a factor of two, indicating that single linear extension growth rates are not valid. This type of growth rate variation has been observed in other coralline sponges such as *Ceratoporella nicholsoni* (Swart

et al. 2002; Willenz and Hartman 1999). Some of the growth rate variability within an individual may be due to errors associated with matching the two $\Delta^{14}\text{C}$ curves or to the time error associated with the original coral $\Delta^{14}\text{C}$ records. We estimate that the time errors associated with the GBR coral $\Delta^{14}\text{C}$ are on the order of 1 to 2 y because they are based on density band counting and sampling resolution. This would correspond to a ~ 0.1 to 0.2 mm y^{-1} error in our within-individual extension rates. Estimates of the error associated with matching the two curves are more difficult because they depend on the number of marker points. For this study, we will assume that the majority of the error is associated with the original coral $\Delta^{14}\text{C}$ time series.

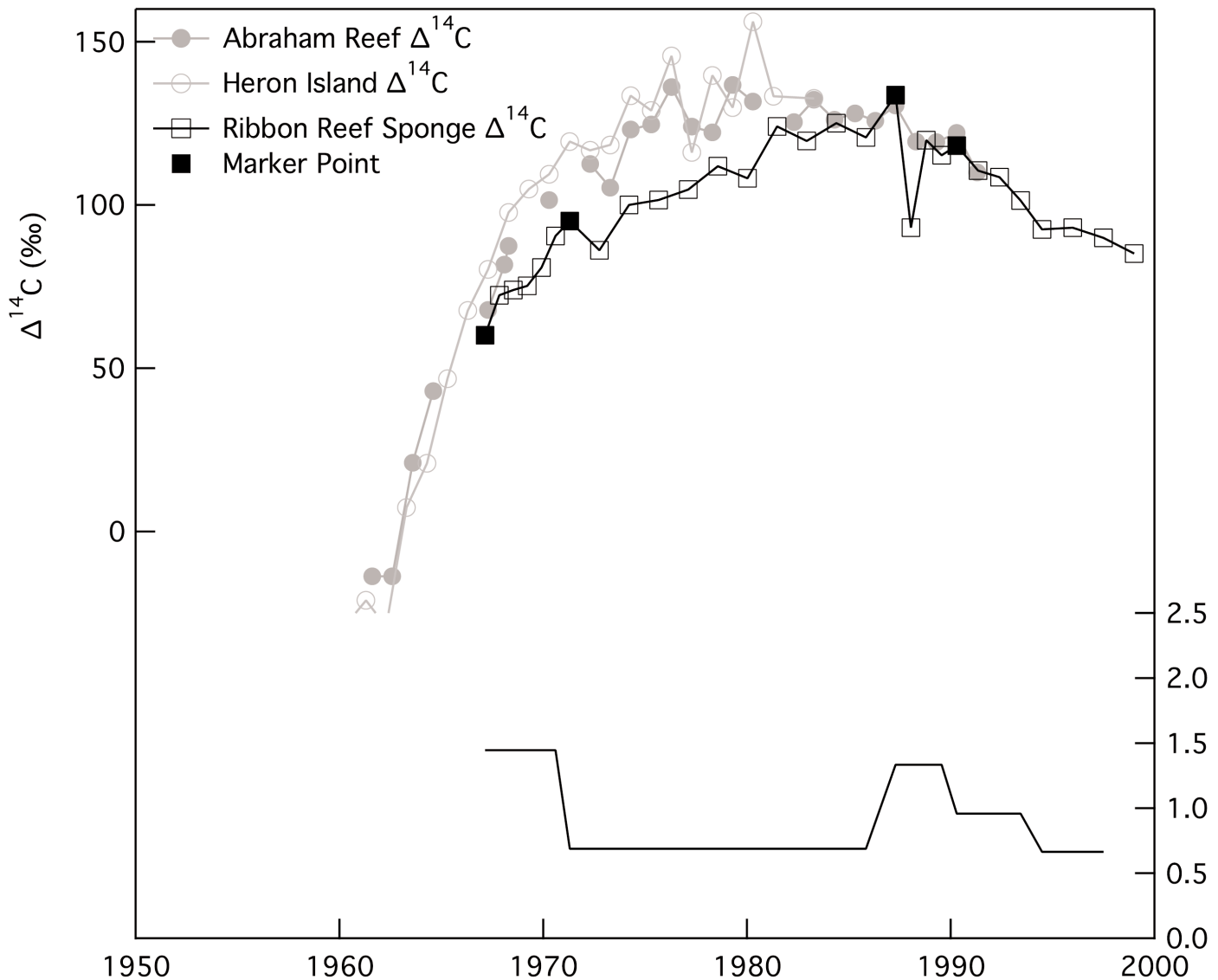


Fig. 4. Upper portion: *Astrosclera willeyana* sample from Ribbon Reef nr 10 fit to the Heron Island and Abraham Reef corals (Druffel and Griffin 1995). Lower portion: Growth rate of sponge from fit to GBR corals using marker points. Sponge $\Delta^{14}\text{C}$ errors are the size of the symbols.

Both the Myrmidon and Ribbon Reef samples display increasing $\Delta^{14}\text{C}$ near the base of the sample (Fig. 2). Sampling near the base of the sponge may be problematic: multiple time lines may be intersected depending on the “tightness” of the concentric growth lines (*see* cartoon overlay in Fig. 1) as well as secondary infilling of carbonate in the borings (borings at the base of the samples were visible and impossible to completely avoid). We attribute the incongruous $\Delta^{14}\text{C}$ results at the base to these processes. This is not a problem away from the base of the sponge.

There are no coral $\Delta^{14}\text{C}$ datasets available from the Caroline Islands. Instead, we chose a high-resolution coral from Nauru (Guilderson et al. 1998) to compare with the Truk sponge sam-

ple (Fig. 5). This is not as robust a comparison as for the GBR samples, but it is sufficient to provide gross extension rates for this sample. Using this method we obtain an average extension rate of $1.2 \pm 0.1 \text{ mm y}^{-1}$, although this is only based on the collection date and one marker point.

Comparison with other published Astrosclera willeyana growth rates—The data presented here suggest that the coralline sponge *Astrosclera willeyana* has a growth (extension) rate of $\sim 1.1 \text{ mm y}^{-1}$ but the growth rate can vary by a factor of two. This is substantially different from the growth rate estimated by Wörheide (1998): the growth rate estimated using Calcein- Na_2 was 0.23 mm y^{-1} over a 1-y period. However, using his radiometric data (a single Th/U and ^{14}C date for a large 25 cm

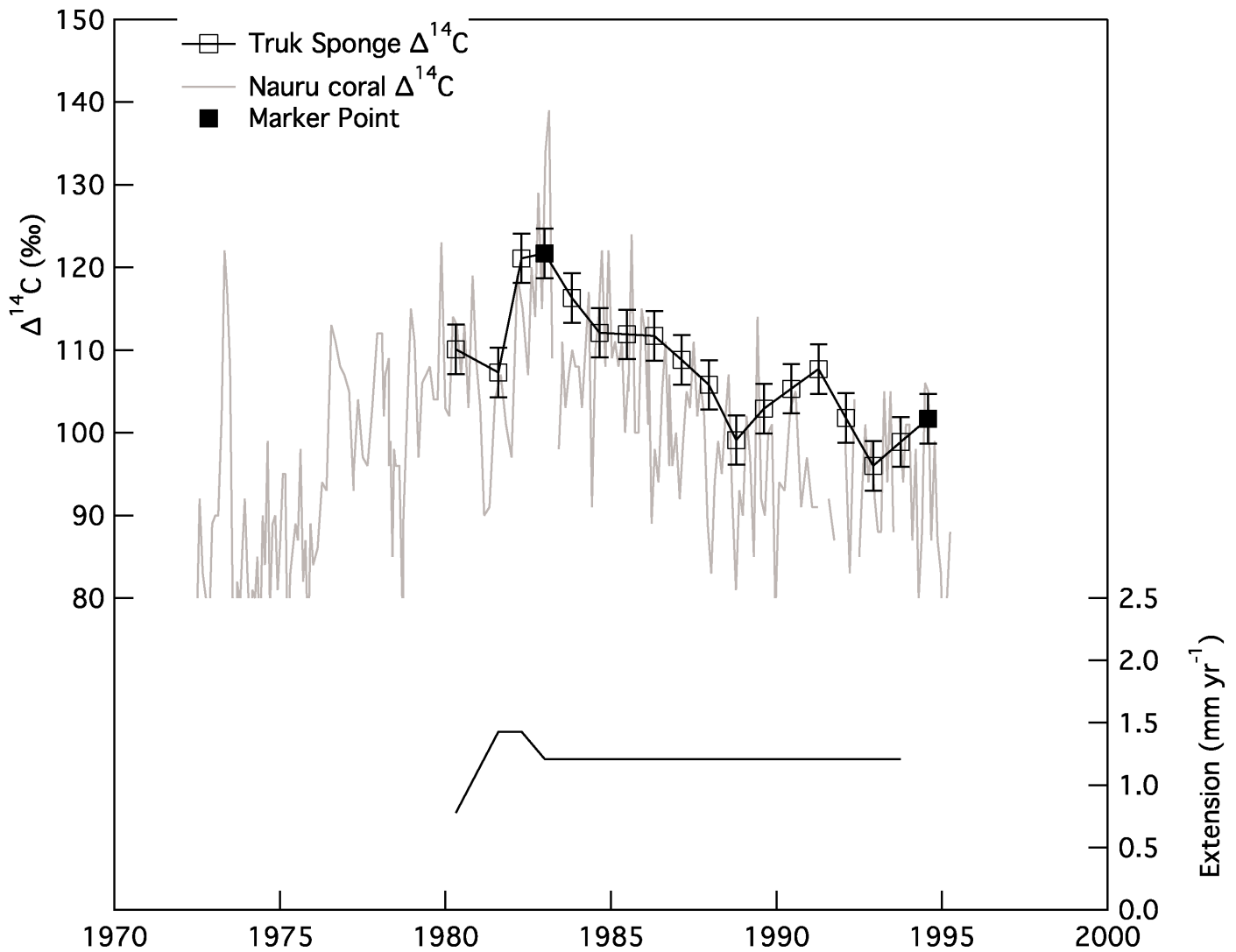


Fig. 5. Upper portion: *Astrosclera willeyana* sample from Truk Lagoon, Caroline Islands, fit to a coral from Nauru (Guilderson et al. 1998). Lower portion: Growth rate of sponge from fit to Nauru coral using marker points. Sponge $\Delta^{14}\text{C}$ error bars are shown.

diameter specimen), one obtains a growth rate that varies from 0.3 to 0.4 mm yr^{-1} depending on where the sample is measured (Wörheide 1998). Their samples were from nearly the same location as the Ribbon Reef sponge sample used in this study. The only other published growth rates of *Astrosclera* are from four samples collected in Indonesia and the Solomon Islands by Moore et al. (2000). They used a single Th/U date for each sample and obtained growth rates of 0.7, 0.6, 0.4, and 0.7 mm yr^{-1} for Kapota, Solomon, Kapoposang and Bunaken, respectively (Moore et al. 2000). Because of the large amount of sample needed for the Th/U analysis, the uncertainty in the growth rate determined by this method is probably $\pm 10\%$ to 20%. Nonetheless their values are in reasonable agreement with the ones determined in this study. More disturbing, how-

ever, is the difference between the growth rates measured by staining (Wörheide 1998) and the bomb radiocarbon method proposed here. At this point, we cannot attribute a cause to the substantial differences in growth rate estimates. Some variability can be accounted for if one measures the length (extension) of the transect from different points on the outer edge of the sample. For instance, the apparent growth rates can be different if the sponge is wider than it is tall, although not by a factor of 6, as in this case.

Discussion

If the *Astrosclera* sponge growth rates can vary from 0.2 to 1.2 mm yr^{-1} in individuals collected within 1 km in the GBR, it would be ill advised to assume a universal or aver-

age growth rate. Individual specific growth rate information would be required to place paleo-environmental data on an accurate temporal framework. There also appears to be some variability in the growth rate on annual or longer time scales. We recommend a multi-point age model to account for these possible growth rate variations and obtain the best and most accurate time series of environmental variables from *Astrosclera*. For samples that are collected near available coral time series, radiocarbon profiles provide a good age constraint for the 1945 to present time period. For samples older than that, one can augment the age model with Th/U dates.

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Submitted 6 July 2004

Revised 17 February 2005

Accepted 17 August 2005