Linear Extension Rates of Massive Corals from the Dry Tortugas National Park (DRTO), Florida

By Adis Muslic, Jennifer A. Flannery, Christopher D. Reich, Daniel K. Umberger, Joseph M. Smoak, and Richard Z. Poore

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Contents

Figures

Tables

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Abstract

Colonies of three coral species, *Montastraea faveolata*, *Diploria strigosa*, and *Siderastrea siderea*, located in the Dry Tortugas National Park (DRTO), Florida, were sampled and analyzed to evaluate annual linear extension rates. *Montastraea faveolata* had the highest average linear extension and variability in (DRTO: C2 = 0.67 centimeters/year (cm yr^{-1}) ± 0.04, B3 = 0.85 cm yr^{-1} ± 0.07), followed by *D. strigosa* (DRTO: C1 = 0.73 cm yr^{-1} ± 0.04; MK = 0.59 cm yr^{-1} ± 0.06) and *S. siderea* (DRTO: A1 = 0.41 cm yr^{-1} ± 0.03). Intercolony comparison of *M. faveolata* from DRTO yielded a significant correlation ($r = 0.34$, $df = 67$, $P = 0.005$) and similar long-term patterns. DRTO *S. siderea* core A1 showed an overall increasing trend ($r = 0.61$, $df = 119$, $P < 0.0001$) in extension rates that correlated significantly with International Comprehensive Ocean/Atmosphere Data Set annual sea-surface temperature ($r = 0.42$, $df = 115$, $P < 0.0001$) and an air temperature record from Key West ($r = 0.37$, $df = 111$, $P < 0.0001$). In conclusion, annual linear extension rates are species specific and potentially influenced by long-term variability in sea-surface temperature.

Introduction

Massive reef-building scleractinian corals have the potential for providing detailed information about past environmental conditions and the response of coral reefs to environmental change. The coral skeletons are composed of calcium carbonate in the form of the mineral aragonite. These corals are long-lived (multicentury), and their skeletons exhibit distinct annual density banding. A couplet of high and low density bands represents 1 year of growth. Some species, such as *Montastraea faveolata*, form their high density bands during the summer months, and lower density bands are deposited during the rest of the year (Shinn, 1966; Swart and others, 2002). The annual banding of the skeleton allows precise chronology, coral linear extension rates, and guidance of subannually resolved sampling for geochemical or isotopic analyses.

Changes in the width of annual growth bands, or annual extension rates, of coral skeletons represent one measure of coral growth that can be related to coral health. Coral extension rates are species specific (Buddemeier and others, 1974; Tomascik, 1990; Logan and others, 1994). Buddemeier and others (1974) measured the extension rates of 47 reef-building corals of 15 different species and found that coral linear extension rates were more influenced by species than any environmental factor. However, studies measuring linear extension rates within individual species indicate that a variety of factors correlate with (and may influence) coral linear extension rates. Correlates of mean annual extension rates include season, rainfall (Buddemeier and others, 1974; Alibert and McCulloch, 1997), the El Niño Southern Oscillation (ENSO) cycle (Alibert and McCulloch, 1997), light levels (Bak, and others, 2009), and location within the reef (Cruz-Pinon and others, 2003).

A number of studies suggest that temperature may be an important control on linear extension rate variability in corals (Shinn, 1966; Carricart-Ganivet, 2004; De'ath and others, 2009), but the results of other studies are conflicting. Some studies indicate that linear extension rates in corals decrease as a result of an increase in sea-surface temperature (SST) (Carricart-Ganivet, 2004; Cooper and others, 2008; De'ath and others, 2009). For example, specimens of genus *Porites* from the Great Barrier Reef (GBR) experienced a 16 percent decline in extension rates (Cooper and others, 2008). Extension rates in these *Porites* specimens decreased 1.02 percent yr^{-1} from 1988 to 2003 as a result of a rise in SST (Cooper and others, 2008). Carricart-Ganivet (2004) determined that decreasing trends in linear extension rates are correlated with increasing SST by measuring linear extension rates from *Montastraea annularis* from six locations across the Gulf of Mexico.

Other studies concluded that linear extension rates increased with increasing SST (Shinn, 1966; Dodge and Lang, 1983). Dodge and Lang (1983) found that extension rates in *M. annularis* from the Gulf of Mexico increased with increasing SST. Additionally, some other studies concluded that SST had no significant correlation with coral extension rates (Gladfelter and others, 1978; Bak and others, 2009; Helmle and others, 2011).

A study was conducted by the U.S. Geological Survey (USGS) to report linear extension rate measurements for several common massive reef building corals in the Dry Tortugas National Park (DRTO), Florida. The study included three species (*Siderastraea siderea*, *Montastraea faveolata*, and *Diploria Strigosa*) of coral collected from the DRTO.

Study Site

The DRTO (fig. 1) is located 112.9 kilometers (km) west of Key West, Florida (*http://www.nps.gov/drto/index.htm*), the closest inihabited area to the park. The DRTO forms an elliptical atoll-like structure that is 27 km along the major axis (southwest-northeast) and 12 km along the minor axis (Davis, 1982). The three major banks—Pulaski Shoal (northeast), Long Key (south), and Loggerhead Key (west)—are separated by 10–20 meter (m) deep channels. The average water depth of the banks is 2–3 m, and the banks are surrounded by 12–23 m deep lagoons. The Holocene reefs composing the DRTO are situated on the South Florida margin and occupy a transitional zone between the south- and east-facing rimmed margin and the west-facing ramp margin (Mallinson and others, 2003). The reefs are situated on the Key Largo Limestone platform composed mainly of older (~125 thousand years old) massive coral heads (Hickey and others, 2012).

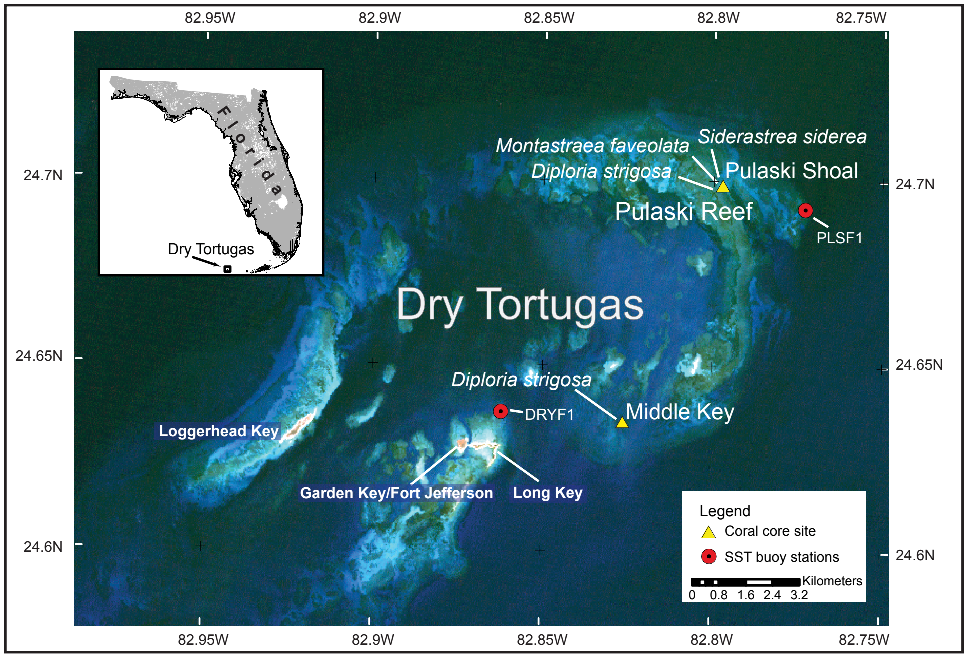

Figure 1. Map of the Dry Tortugas National Park (DRTO), Florida. The coral core locations and Coastal Marine Automated Networks (C-MAN) stations monitoring SST are denoted on the map by yellow triangles and red circles, respectively. All modern *Montastraea faveolata*, *Siderastrea siderea*, and *Diploria strigosa* coral cores were collected from Pulaski Shoal, and one *D. strigosa* coral core was collected from Middle Key in August 2008.

Materials and Methods

Coral Collection

The DRTO coral cores were collected from Pulaski Shoal and Middle Key, Florida, in August 2008. The cores were collected from live coral heads at water depths ranging from 3.4 to 4.3 m (table 1), using the USGS rotary hydraulic coring system.

Table 1. Summary of data for cores collected at the Dry Tortugas National Park (DRTO), including collection date, site and reef names, location (latitude and longitude), water depth, and core length.

Core	Date	Location	Coral Species	Latitude (N)	Longitude (W)	Water Depth (m)	Core Length (cm)
B3	8/7/2008	Pulaski Shoal	*Montastraea faveolata*	24.699	82.799	3.4	142
C2	8/8/2008	Pulaski Shoal	*Montastraea faveolata*	24.695	82.795	3.7	156
C1	8/7/2008	Pulaski Shoal	*Diploria strigosa*	24.699	82.798	3.4	60
MK	8/6/2008	Middle Key	*Diploria strigosa*	24.645	82.832	3.4	23
A1	8/6/2008	Pulaski Shoal	*Siderastrea siderea*	24.699	82.798	4.3	113

The equipment used for drilling included a hydraulic-powered submersible drill, a 10-centimeter (cm) diameter by 61-cm long core barrel with a surface set diamond bit and a hydraulic power unit operated from the boat. Corals were drilled along their vertical growth. Following drilling, cores were taken to the USGS Coastal and Marine Science Center in St. Petersburg, Florida, where they were cut into 5 millimeter (mm) thick slabs along their maximum growth axis (Reich and others, 2009; Hickey and others, 2012). The DRTO slabs were x-rayed at Louisiana State University by an AGFA CR 35-X machine at 55 kiloVolts (kV) for 2.5 milliAmp seconds (mAs). The x-ray images were converted into Adobe Photoshop files with 100 pixel cm^{-1} resolution.

Linear Extension Rates

Extension rate measurements were made on coral x-ray images using the ruler tool in Adobe Photoshop. Measurements were made along the thecal wall, a part of the skeleton where calcium carbonate is deposited continuously and high and low density bands are distinguished. Linear distance between the tops of successive high density bands was measured. Since the high density bands are formed during the late summer and early fall (Swart and others, 2002), a coral year does not correspond to a calendar year. For consistency, in comparisons to other parameters, it is assumed that each coral year starts on the 1^{st} day of September.

Eight flat coral slabs from five different DRTO cores from three different species (*M. faveolata, S. siderea,* and *D. strigosa*) were analyzed from the DRTO (nomenclature for cores and slabs used in this text is found in table 1). Intracolony replication was performed on two slabs of *M. faveolata* and *S. siderea*, and intercolony comparison was done on two different *M. faveolata* and *D. strigosa* colonies. In an effort to reduce measuring errors, paths with clear, distinguished high and low density bands were chosen over those with less clear banding. At least three linear extension transects for each year were measured from each DRTO coral slab.

Siderastrea siderea deposits calcium carbonate more evenly throughout the year, causing high and low density bands to be less distinctive than the other two species, proving more difficult to designate a starting and ending point of each density band. *Montastraea faveolata* polyps tend to have meandering paths that grow at an angle, which appear shorter or longer on the x-ray than they actually are, leading to incorrect measurements. To avoid this discrepancy, paths were measured until meandering started, then another path was chosen for measuring.

The coral density bands on the x-rays were counted backward from 2008 down core for DRTO corals, excluding year 2008 because data for this year were incomplete and lacked high density band formation. In cases where multiple slabs were analyzed for the same core, the results were averaged to form a composite record. Statistical calculations were made using Microsoft Office Excel 2010 by applying standard statistical procedures for average and standard deviation. Correlations between coral linear extension rates and environmental parameters (including SST) were made using standard linear regression with 95 percent confidence interval (α=0.05).

Results and Discussion

Montastraea faveolata had the highest average extension rate and variability of all three species from DRTO. The average linear extension rates of *M. faveolata* cores (fig. 2A–D; C2 = 0.67 cm yr^{-1} ± 0.04 (n = 69 (number of years)); B3 = 0.85 cm yr^{-1} ± 0.07 (n = 119)) were within the range (0.38 to 0.98 yr^{-1}) for this species for studies throughout the Caribbean (Carricart-Ganivet and others, 2000; Helmle and others, 2011). For example, average linear extension rates for *M. faveolata* varied from

0.38 cm yr $^{-1}$ in Discovery Bay, Jamaica (Dustan, 1975), to 0.87 cm yr $^{-1}$ in the Mexican Caribbean Carricart-Ganivet and others, 2000), and 0.91 cm yr $^{-1}$ to 0.98 cm yr $^{-1}$ in St. Croix, U.S. Virgin Islands (Baker and Weber, 1975; Dodge and Brass, 1984, respectively).

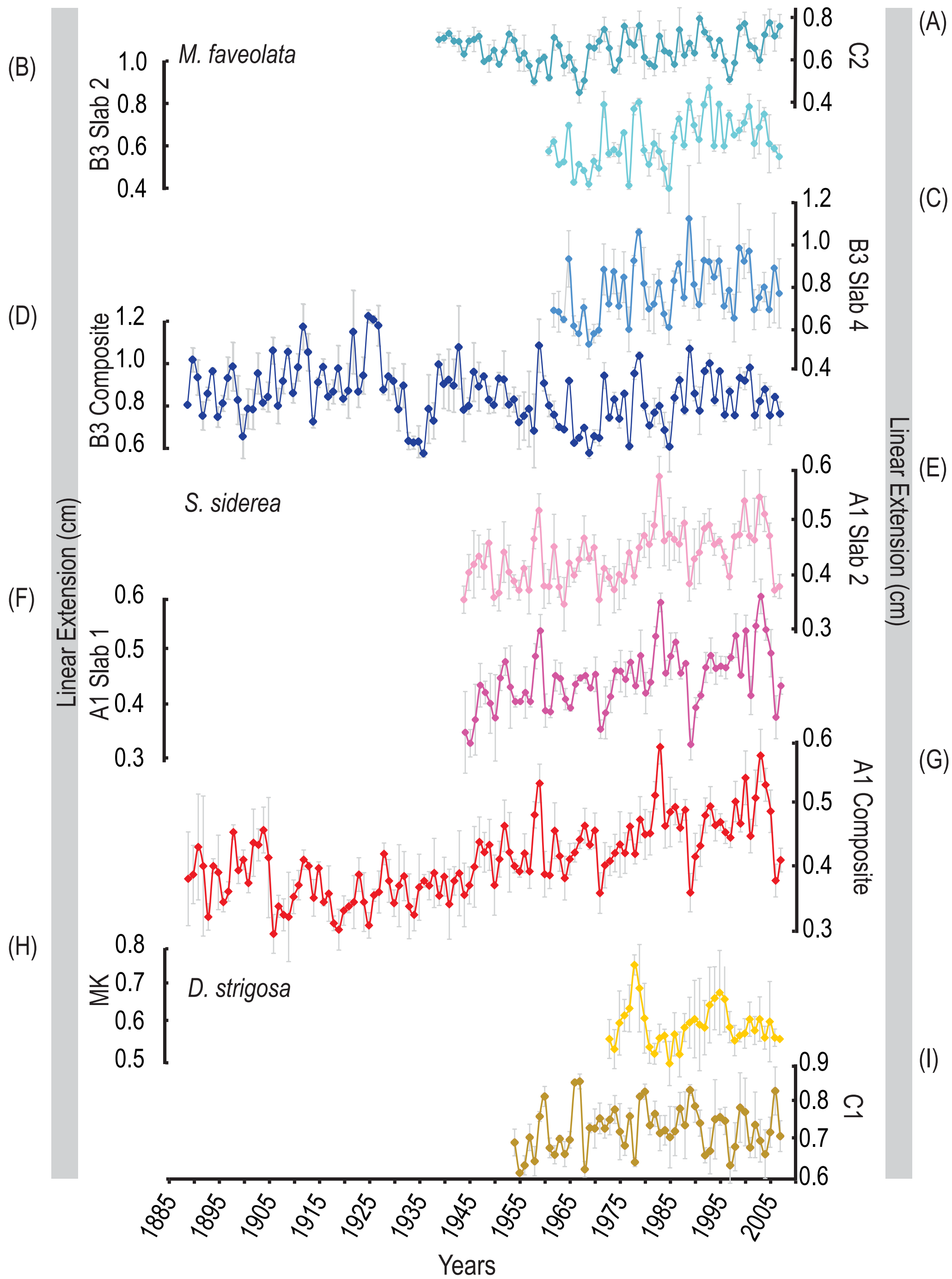

Figure 2. Average annual linear extension rates (in centimeters) for all DRTO coral cores from 1889 to 2007 with error bars (1σ). Y-axis scales were adjusted for each coral to show variability. (A) *M. faveolata* C2 (B) *M. faveolata* B3 Slab 2 (C) *M. faveolata* B3 Slab 4 (D) *M. faveolata* B3 Composite (E) *S. siderea* A1 Slab 2 (F) *S. siderea* A1 Slab 1 (G) *S. siderea* A1 Slab 2 Composite (H) *D. strigosa* MK (I) *D. strigosa* C1.

Intracolony correlation between different slabs from the same species (slabs 2 and 4) was high in *M. faveolata* B3 (fig. 3A, r = 0.82, df = 44, P < 0.0001), most likely resulting from a combination of genetics (because they are from the same colony; (Oliver, 1968)) and picking paths with similar coral polyp orientation.

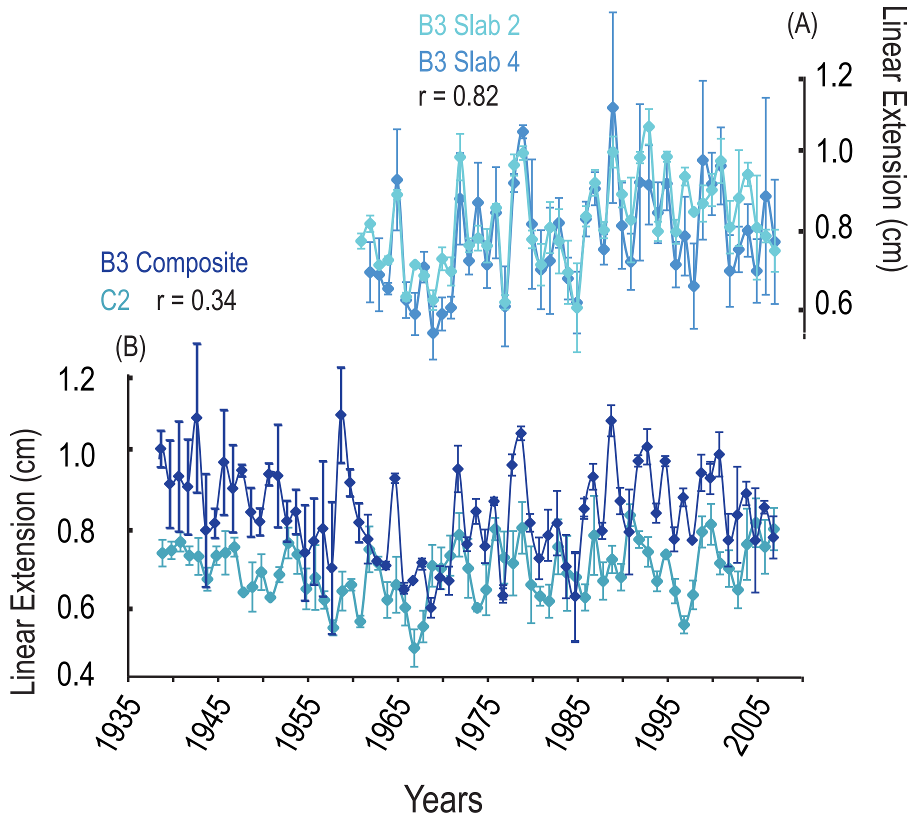

Figure 3. (A) Average annual linear extension rates (in centimeters) comparison for *M. faveolata* B3 Slab 2 (light blue) and B3 Slab 4 (dark blue) from 1960 to 2007 with error bars (1σ). (B) Average annual linear extension rates (in centimeters) comparison for *M. faveolata* B3 Composite (navy blue) and C2 (teal) from 1938 to 2007 with error bars (1σ).

Intracolony *M. faveolata* slabs had a higher correlation than intercolony *M. faveolata* slabs. *Montastaea faveolata* cores B3 and C2 had a significant positive correlation with each other (fig. 3, r = 0.34, df = 67, P = 0.0043), although *M. faveolata* core B3 had a 25.4 percent higher average extension rate than *M. faveolata* C2. Both *M. faveolata* cores B3 and C2 showed a slight negative trend until the late1960s (fig. 3B). It is likely that both *M. faveolata* colonies experienced similar environmental conditions because they were collected from the same reef patch from similar water depths (~3.5 m; table 1).

Siderastraea siderea

Of the three DRTO species, *Siderastrea siderea* A1 had the lowest extension rates (0.41 cm $yr^{-1} \pm 0.03$ (n = 119), fig. 2D,E), approximately 0.3 cm yr^{-1} less than those determined from *S. siderea* specimens from Panama (Guzman and Tudhope, 1998) but similar to *S. siderea* specimens from Puerto

Rico (0.35 to 0.43 cm yr $^{-1}$; Torres and Morelock, 2002). Like *M. faveolata*, two intracolony slabs from *S. siderea* A1 were highly correlated with one another (fig. 3A, r = 0.95, df = 62, P < 0.0001). Intracolony comparison of *S. siderea* reveals a higher correlation (r = 0.95) than that of *M. faveolata* (r = 0.82).

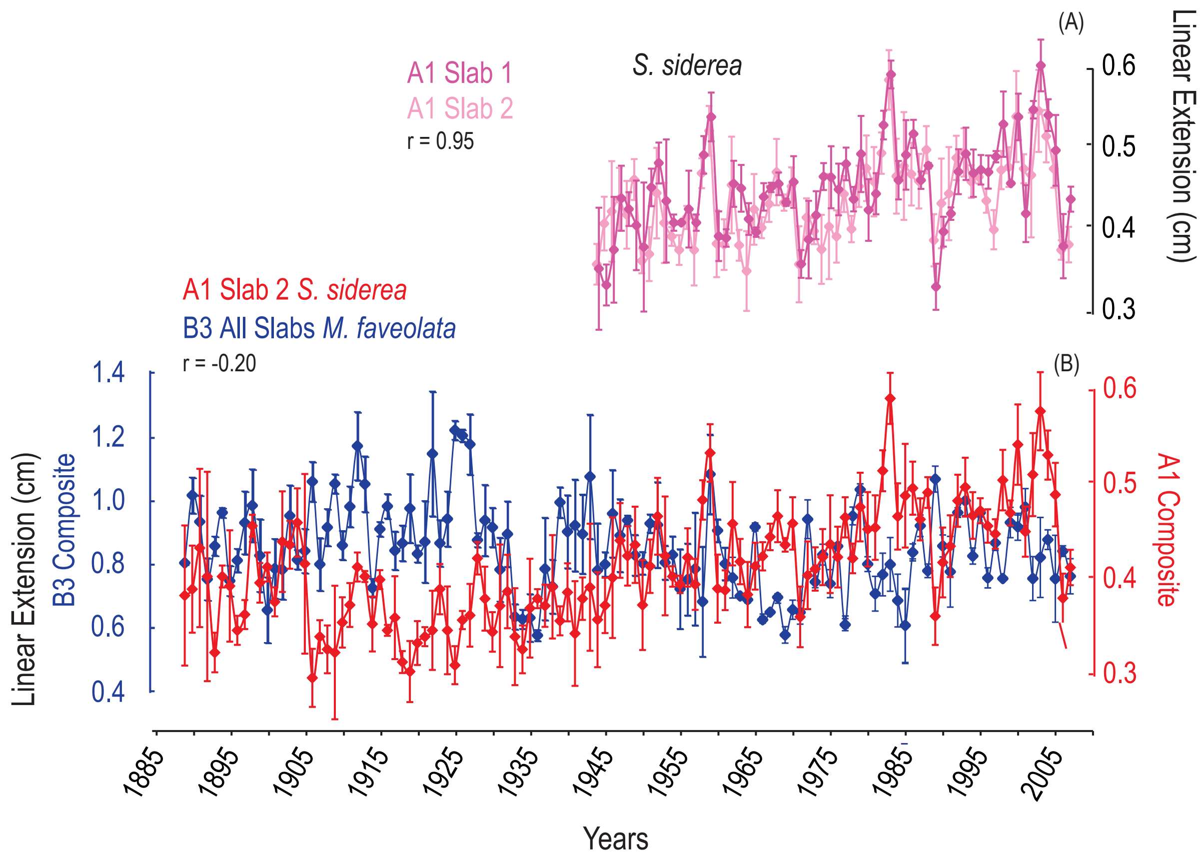

Figure 4. (A) Average annual linear extension rates (in centimeters) comparison for *S. siderea* A1 Slab 1 (pink) and A1 Slab 2 (red) from 1944 to 2007 with error bars (1σ). (B) Average annual linear extension rates (in centimeters) comparison for *S. siderea* A1 Composite (red) and *M. faveolata* B3 Composite (navy blue) from 1889 to 2007 with error bars (1σ). Y-axis scales were adjusted for each coral to show variability.

Montastraea faveolata B3 had a significant negative correlation with *S. siderea* A1 (fig. 4B, r = –0.20, df = 117, P = 0.0292). *Siderastrea siderea* A1 had a significant overall positive trend (r = 0.61, df = 119, P < 0.0001) in linear extension rates from 1889 to 2007, while *M. faveolata* B3 had a signifcant negative trend for the same time interval (r = –0.22, df = 119, P = 0.0153). This suggests that fast-growing *M. faveolata* reacts differently to similar environmental conditions compared to slow-growing *S. siderea*.

Differences in growth strategies among these species may have contributed to their different responses to environmental challenges. For example, a *S. siderea* from Puerto Rico was found to be tolerant to sedimentation while *Montastraea annularis* was sensitive to sedimentation (Torres and Morelock, 2002). This implies that coral species respond differently to similar localized environmental conditions. Although the aforementioned study focused on sedimentation, it is conceivable that different coral species may respond differently to other environmental conditions as well, such as SST. Local environmental factors may cause extension rates to vary, even in corals that live in close proximity to each other (Heiss, 1996).

Diploria strigosa

The average extension rates (C2: 0.73 cm yr $^{-1}$ ± 0.04 (n = 54), MK: 0.59 cm yr $^{-1}$ ± 0.06 (n = 35)) and variability in *Diploria strigosa* were lower than those of *M. faveolata* but higher than that of *S. siderea* (fig. 2). *D. strigosa* C1 had extension rates on average 19.6 percent higher than *D. strigosa* MK, and no similar trends or correlations were observed between the two *D. strigosa* cores. X-rays of *D. strigosa* C1 revealed that the coral had a hyperplasia tumor, typically known to increase coral cell growth leading to abnormally high extension rates (Gateño and others, 2003), as observed in this core. *Diploria strigosa* MK extension rates were closer to those found elsewhere in the Caribbean Sea and the Gulf of Mexico, suggesting normal growth (0.25 cm yr $^{-1}$ to 0.42 cm yr $^{-1}$, Logan and others, 1994). Other *D. strigosa* linear extension rates measured in various locations across the West Atlantic included 0.46–0.59 cm yr $^{-1}$ in Panama (Guzman and Cortes, 1989), 0.43–0.46 cm yr $^{-1}$ in Aruba (Harriot, 1992), 0.35–1.00 cm yr $^{-1}$ in Bahamas (Hubbard and Scaturo, 1985), 0.5 cm yr $^{-1}$ in East Flower Banks (Hudson and others, 1994), and 0.33 cm yr $^{-1}$ in Bermuda (Johannes and others, 1983). The average extension rate of 0.59 cm yr $^{-1}$ in *D. strigosa* MK is above regional average but still within the range for the species collected near the Gulf of Mexico.

Environmental Factors

Sea-Surface Temperature

Several studies proposed that SST is a leading cause of extension rate variability in corals (Shinn, 1966; Carricart-Ganivet, 2004; De'ath and others, 2009). Three temperature data sets were available in proximity to the coral coring locations: local buoy SST (DRYF1 and PLSF1), Key West air temperature, and the International Comprehensive Ocean-Atmosphere Data Set (ICOADS) SST. Local buoy data sets were collected from Coastal Marine Automated Network (C-MAN) stations PLSF1 (fig. 1; 24.69°N, 82.77°W) and C-MAN DRYF1 (fig. 1; 24.64°N, 82.86°W). Both stations are located within the boundaries of DRTO (PLSF1 was located at Pulaski Shoal near the locations of the corals). All buoy values were obtained hourly and were computed into average monthly and mean annual SST values. Five complete years of data were available for annual comparisons, making this record the shortest of all three records available. The local buoys likely produced the most comparable SST records, but the records do not cover the necessary time interval. ICOADS SST data contain observations by ships and buoys and are considered by the National Oceanic and Atmospheric Administration (NOAA) to be one of the most complete and heterogeneous collections of SST (*http://icoads.noaa.gov/*). ICOADS contains the SST for the past 300 years and is arranged in 2° latitude by 2° longitude boxes prior to 1959 and 1° by 1° since 1960. The grids used in this study were centered on 82°W and 24°N. Gridded SST data sets such as ICOADS are widely used in coral studies (Payet and Agricole, 2006; Vargas-Angel and others, 2006; Guzman and others, 2008). Lastly, Key West air temperature was recorded daily and sensors were maintained by the National Weather Service (Menne and others, 2011). Air temperature was measured 1.22 m above sea level at the Key West International Airport (station 084570) from 1895 to 2007. The mean annual Key West air temperature record was compared to the linear extension rates to potentially compensate for the increased ICOADS grid size prior to 1960.

Mean annual ICOADS SST correlated significantly with *S. siderea* A1 linear extension rates (fig. 5A,B; r = 0.42, df = 115, P < 0.0001) but not with the extension rates of the other corals. The mean annual Key West air temperature data also correlated significantly with the A1 linear extension rates (fig. 5B,C; r = 0.37, df = 111, P < 0.0001). Slow-growing *S. siderea* produces short yet steady extension rates. The extension rates of the fast-growing *M. faveolata* and *D. strigosa* had no significant correlation with annual SST. The DRTO results agree with Helmle and others (2011) who found no correlation between *M. faveolata* extension rates and SST from Florida Keys. In agreement with other studies, the linear extension rates were species specific (fig. 2; Buddemeier and others, 1974; Tomascik, 1990; Logan and others, 1994).

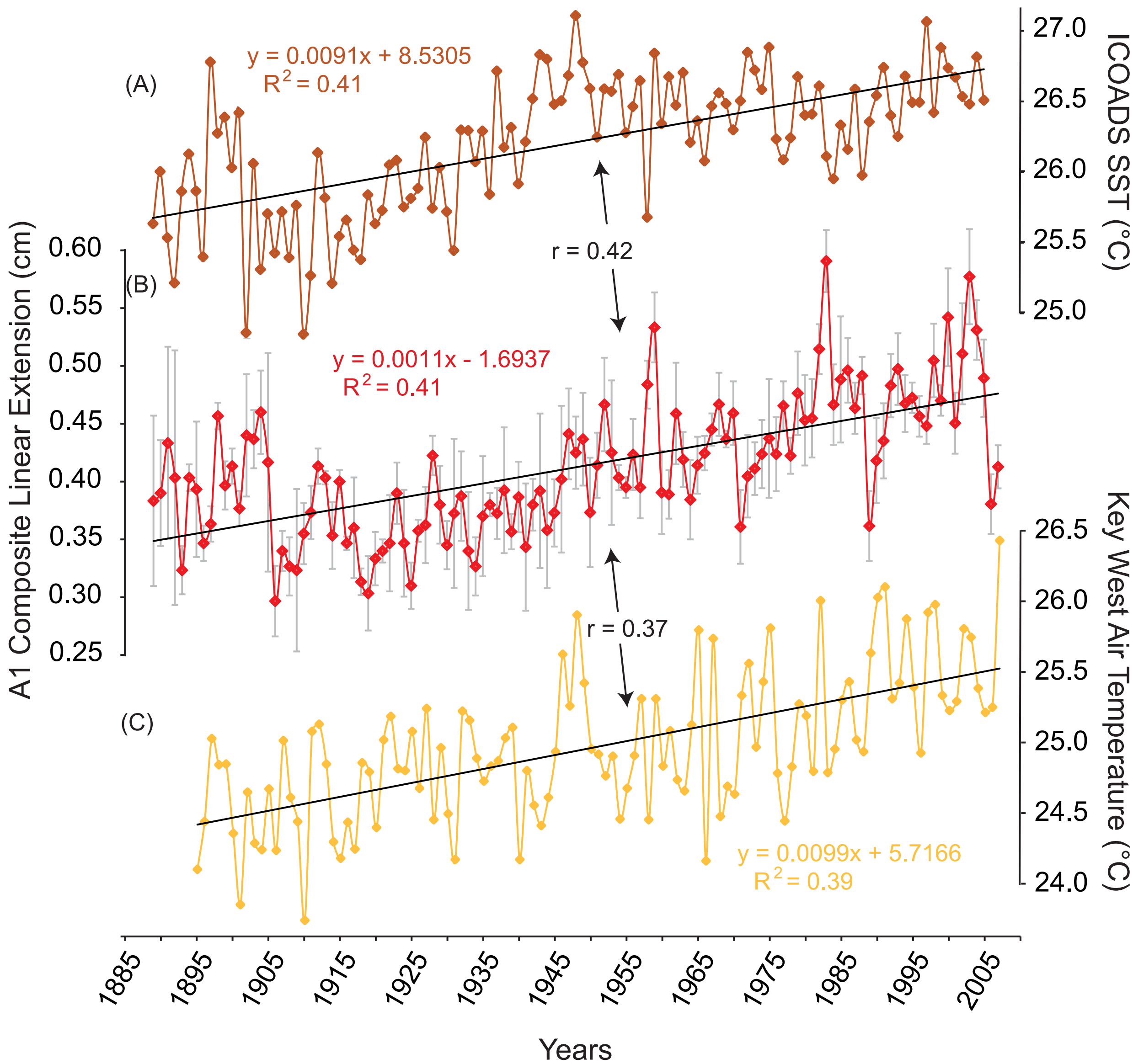

Figure 5. (A) Gridded mean annual ICOADS data set centered on 82°W and 24°N from 1889 to 2007 (orange curve). (B) Average annual linear extension rates (in centimeters) for S. siderea A1 Composite (red curve) with error bars (1s). (C) Mean annual Key West air temperature from 1889 to 2007 (yellow curve).

Conclusions

The current study documents linear extension rates for three massive coral species (*Montastraea faveolata, Siderastrea siderea*, and *Diploria strigosa*). It can be concluded that extension rates in the Dry Tortugas National Park are species specific as well as colony specific. *Montastraea faveolata* had the highest linear extension rates (fastest growth) of all three species in DRTO, and *S. siderea* had the lowest (slowest growth). Intracolony comparisons of both *M. faveolata* and *S. siderea* demonstrate that environmental factors influence each polyp within the colony in a similar way. Intercolony comparisons in *M. faveolata* from DRTO had a significant positive correlation.

Siderastrea siderea and *M. faveolata* produced long linear extension rate records. DRTO *S. siderea* A1 had an overall positive trend that correlated significantly with ICOADS SST (centered on 24°N and 82°W) and an air temperature record from Key West, Fla. Both species merit the attention of future studies in the field of climatology for subtropical and tropical oceans.

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Appendix

DRTO *Montastraea faveolata*

Year	B3 Composite	B3 Composite Error (1σ)	B3 Composite n n	B3 Slab 2	B3 Slab 2 Error (1σ)	B3Slab 2 n	B3 Slab 4	B3 Slab 4 Error (1σ)	B3Slab 4 n	C2	C2 Error (1σ)	C2 n
2007	0.763	0.110	6	0.757	0.056	3	0.77	0.164	3	0.78	0.056	3
2006	0.843	0.138	6	0.796	0.017	3	0.89	0.259	3	0.733	0.071	3
2005	0.756	0.111	6	0.818	0.137	3	0.693	0.084	3	0.797	0.064	3
2004	0.879	0.050	6	0.958	0.031	3	0.8	0.069	3	0.74	0.094	4
2003	0.823	0.093	6	0.896	0.126	3	0.75	0.06	3	0.62	0.049	5
2002	0.756	0.082	6	0.819	0.069	3	0.693	0.095	3	0.676	0.048	5
2001	0.982	0.080	6	0.993	0.058	3	0.97	0.102	3	0.69	0.029	4
2000	0.920	0.062	7	0.917	0.043	3	0.923	0.082	4	0.793	0.054	4
1999	0.933	0.129	7	0.881	0.048	3	0.985	0.209	4	0.773	0.041	4
1998	0.756	0.057	6	0.859	0.002	3	0.653	0.112	3	0.607	0.038	3
1997	0.869	0.064	7	0.952	0.024	3	0.785	0.104	4	0.528	0.023	5
1996	0.758	0.046	6	0.807	0.032	3	0.71	0.06	3	0.617	0.032	3
1995	0.964	0.042	6	1.004	0.014	3	0.923	0.070	3	0.713	0.006	3
1994	0.827	0.053	6	0.808	0.026	3	0.847	0.080	3	0.643	0.026	4
1993	1.002	0.076	6	1.083	0.047	3	0.92	0.104	3	0.72	0.039	4
1992	0.964	0.111	6	1.002	0.015	3	0.927	0.206	3	0.753	0.022	4
1991	0.778	0.093	7	0.838	0.112	3	0.718	0.074	4	0.817	0.029	3
1990	0.859	0.074	7	0.906	0.035	3	0.813	0.114	4	0.653	0.035	3
1989	1.07	0.146	6	1.017	0.041	3	1.123	0.251	3	0.7	0.036	3
1988	0.781	0.031	6	0.811	0.021	3	0.75	0.04	3	0.643	0.049	3
1987	0.923	0.039	6	0.936	0.034	3	0.91	0.044	3	0.763	0.104	3
1986	0.839	0.036	7	0.848	0.027	4	0.83	0.046	3	0.6	0.035	3
1985	0.608	0.099	8	0.607	0.117	4	0.61	0.081	4	0.653	0.006	3
1984	0.687	0.069	7	0.7	0.083	4	0.673	0.055	3	0.663	0.099	3
1983	0.801	0.075	7	0.782	0.085	4	0.82	0.066	3	0.733	0.072	3
1982	0.769	0.104	6	0.818	0.067	3	0.72	0.14	3	0.59	0.044	3
1981	0.708	0.080	6	0.72	0.055	3	0.697	0.104	3	0.603	0.025	3
1980	0.802	0.097	6	0.787	0.023	3	0.817	0.170	3	0.633	0.101	3
1979	1.037	0.018	8	1.014	0.018	5	1.06	0.017	3	0.783	0.068	3

DRTO *Montastraea faveolata* (continued)

1978	0.954	0.026	8	0.983	0.028	4	0.925	0.024	4	0.69	0.085	4
1977	0.611	0.062	6	0.621	0.019	3	0.6	0.105	3	0.705	0.069	4
1976	0.858	0.065	6	0.87	0.01	3	0.847	0.120	3	0.78	0.029	4
1975	0.74	0.053	7	0.77	0.044	3	0.71	0.062	4	0.62	0.067	4
1974	0.832	0.069	6	0.79	0.033	3	0.873	0.105	3	0.573	0.010	4
1973	0.746	0.027	6	0.771	0.018	3	0.72	0.036	3	0.677	0.078	3
1972	0.943	0.091	6	1.003	0.061	3	0.883	0.121	3	0.765	0.057	4
1971	0.649	0.033	6	0.702	0.037	3	0.597	0.029	3	0.71	0.053	3
1970	0.658	0.037	6	0.736	0.030	3	0.58	0.044	3	0.677	0.055	3
1969	0.578	0.048	6	0.627	0.026	3	0.53	0.07	3	0.683	0.055	3
1968	0.697	0.026	6	0.691	0.011	3	0.703	0.040	3	0.523	0.042	3
1967	0.65	0.030	6	0.72	0.003	3	0.58	0.056	3	0.467	0.049	3
1966	0.626	0.029	6	0.636	0.011	3	0.617	0.047	3	0.573	0.047	3
1965	0.919	0.073	6	0.904	0.013	3	0.933	0.133	3	0.633	0.074	3
1964	0.689	0.013	6	0.732	0.010	3	0.647	0.015	3	0.593	0.047	3
1963	0.701	0.051	6	0.719	0.005	3	0.683	0.096	3	0.69	0.017	3
1962	0.759	0.051	6	0.828	0.022	3	0.69	0.079	3	0.727	0.060	3
1961	0.803	0.051	3	0.782	0.020	3				0.537	0.015	3
1960	0.908	0.036	3							0.633	0.015	3
1959	1.086	0.125	3							0.617	0.051	3
1958	0.683	0.174	3							0.52	0.02	3
1957	0.787	0.178	3							0.593	0.023	3
1956	0.753	0.114	3							0.653	0.085	4
1955	0.723	0.126	3							0.623	0.054	4
1954	0.831	0.059	3							0.713	0.051	3
1953	0.807	0.054	3							0.743	0.040	3
1952	0.926	0.135	3							0.66	0.02	3
1951	0.93	0.029	3							0.6	0	3
1950	0.805	0.036	4							0.667	0.047	3
1949	0.83	0.064	3							0.628	0.065	4
1948	0.94	0.015	3							0.613	0.006	3
1947	0.892	0.115	3							0.733	0.025	4
1946	0.961	0.138	3							0.718	0.057	4

DRTO *Montastraea faveolata* (continued)

1945	0.801	0.039	3							0.71	0.025	4
1944	0.782	0.149	3							0.648	0.030	5
1943	1.078	0.196	3							0.708	0.049	5
1942	0.897	0.125	3							0.71	0.025	5
1941	0.924	0.145	4							0.746	0.025	5
1940	0.904	0.115	4							0.724	0.023	5
1939	0.997	0.048	3							0.717	0.035	3
1938	0.731	0.085	4									
1937	0.787	0.162	4									
1936	0.577	0.017	3									
1935	0.632	0.075	3									
1934	0.628	0.030	3									
1933	0.636	0.04	3									
1932	0.897	0.103	3									
1931	0.784	0.101	3									
1930	0.918	0.062	3									
1929	0.94	0.112	3									
1928	0.878	0.022	3									
1927	1.18	0.095	3									
1926	1.208	0.019	3									
1925	1.224	0.030	3									
1924	0.944	0.087	3									
1923	0.868	0.073	3									
1922	1.15	0.197	3									
1921	0.872	0.129	3									
1920	0.834	0.027	3									
1919	0.978	0.108	3									
1918	0.868	0.056	3									
1917	0.844	0.061	3									
1916	0.984	0.039	3									
1915	0.912	0.023	3									
1914	0.727	0.029	3									
1913	1.054	0.088	3									

DRTO *Montastraea faveolata* (continued)

1912	1.174	0.108	3									
1911	0.983	0.064	3									
1910	0.861	0.045	3									
1909	1.056	0.030	3									
1908	0.918	0.058	3									
1907	0.801	0.083	3									
1906	1.062	0.063	3									
1905	0.843	0.070	3									
1904	0.816	0.030	3									
1903	0.954	0.096	3									
1902	0.784	0.094	3									
1901	0.788	0.094	4									
1900	0.657	0.104	3									
1899	0.829	0.115	3									
1898	0.987	0.115	3									
1897	0.932	0.099	3									
1896	0.813	0.037	3									
1895	0.749	0.048	3									
1894	0.964	0.015	3									
1893	0.859	0.030	3									
1892	0.754	0.067	4									
1891	0.936	0.083	3									
1890	1.019	0.056	3									
1889	0.806	0.005	3									
Average	0.85	0.07		0.83	0.04		0.78	0.09		0.67	0.04	

DRTO *Siderastrea siderea*

Year	A1 Composite	A1 Composite Error (1σ)	A1 Composite n	A1 Slab 1	A1 Slab 1 Error (1σ)	A1 Slab 1 n	A1 Slab 2	A1 Slab 2 Error (1σ)	A1 Slab 2 n
2007	0.426	0.017	6	0.439	0.015	3	0.413	0.019	3
2006	0.381	0.033	6	0.381	0.040	3	0.381	0.026	3
2005	0.494	0.039	6	0.499	0.044	3	0.489	0.033	3
2004	0.537	0.023	6	0.542	0.020	3	0.531	0.026	3
2003	0.590	0.037	6	0.603	0.032	3	0.577	0.041	3
2002	0.530	0.027	6	0.549	0.011	3	0.511	0.044	3
2001	0.436	0.031	7	0.421	0.035	3	0.451	0.026	4
2000	0.541	0.036	8	0.54	0.029	4	0.542	0.042	4
1999	0.464	0.008	9	0.458	0.002	4	0.470	0.013	5
1998	0.518	0.036	7	0.531	0.040	3	0.505	0.032	4
1997	0.470	0.011	7	0.491	0.007	3	0.448	0.016	4
1996	0.464	0.019	8	0.472	0.020	3	0.456	0.018	5
1995	0.474	0.016	8	0.475	0.018	4	0.473	0.013	4
1994	0.469	0.027	8	0.471	0.029	4	0.468	0.025	4
1993	0.496	0.032	9	0.495	0.032	5	0.497	0.031	4
1992	0.478	0.028	9	0.473	0.028	5	0.483	0.027	4
1991	0.428	0.020	8	0.421	0.008	3	0.435	0.033	5
1990	0.409	0.028	8	0.399	0.018	3	0.418	0.037	5
1989	0.346	0.029	8	0.331	0.028	3	0.362	0.030	5
1988	0.486	0.010	8	0.48	0.003	3	0.492	0.016	5
1987	0.463	0.016	8	0.462	0.011	3	0.463	0.022	5
1986	0.508	0.023	9	0.519	0.017	4	0.496	0.028	5
1985	0.491	0.049	9	0.493	0.043	4	0.488	0.055	5
1984	0.464	0.029	7	0.462	0.024	3	0.467	0.035	4
1983	0.592	0.022	7	0.592	0.017	3	0.591	0.027	4
1982	0.522	0.020	7	0.53	0.018	3	0.515	0.022	4
1981	0.450	0.030	8	0.446	0.025	3	0.455	0.034	5
1980	0.439	0.039	9	0.426	0.038	3	0.453	0.039	6
1979	0.485	0.042	9	0.494	0.047	3	0.476	0.036	6
1978	0.431	0.015	7	0.439	0.015	3	0.422	0.016	4
1977	0.474	0.021	6	0.482	0.020	3	0.466	0.021	3

DRTO *Siderastrea siderea* (continued)

1976	0.437	0.032	7	0.451	0.032	4	0.424	0.032	3
1975	0.452	0.045	7	0.466	0.038	4	0.437	0.051	3
1974	0.445	0.023	8	0.467	0.017	4	0.424	0.030	4
1973	0.415	0.026	8	0.419	0.030	4	0.411	0.023	4
1972	0.397	0.042	8	0.389	0.048	4	0.405	0.036	4
1971	0.36	0.025	8	0.359	0.017	4	0.361	0.032	4
1970	0.460	0.030	8	0.46	0.032	4	0.459	0.028	4
1969	0.436	0.006	8	0.435	0.004	4	0.437	0.007	4
1968	0.462	0.021	7	0.458	0.014	3	0.467	0.027	4
1967	0.449	0.010	7	0.453	0.006	3	0.445	0.014	4
1966	0.433	0.016	8	0.442	0.017	4	0.425	0.015	4
1965	0.406	0.015	8	0.398	0.006	4	0.414	0.025	4
1964	0.399	0.027	7	0.414	0.020	3	0.384	0.034	4
1963	0.436	0.026	7	0.452	0.029	3	0.419	0.024	4
1962	0.458	0.036	7	0.458	0.028	3	0.459	0.044	4
1961	0.39	0.016	7	0.391	0.011	3	0.389	0.021	4
1960	0.392	0.033	6	0.393	0.031	3	0.391	0.036	3
1959	0.537	0.030	6	0.54	0.03	3	0.533	0.030	3
1958	0.489	0.022	6	0.493	0.023	3	0.484	0.021	3
1957	0.403	0.018	6	0.41	0.01	3	0.395	0.027	3
1956	0.425	0.039	7	0.427	0.047	3	0.423	0.031	4
1955	0.403	0.005	7	0.41	0	3	0.395	0.009	4
1954	0.407	0.010	6	0.41	0.01	3	0.403	0.011	3
1953	0.431	0.069	6	0.437	0.076	3	0.425	0.063	3
1952	0.475	0.033	6	0.483	0.025	3	0.467	0.040	3
1951	0.434	0.026	7	0.453	0.023	3	0.414	0.028	4
1950	0.377	0.063	6	0.38	0.079	3	0.373	0.047	3
1949	0.422	0.048	6	0.407	0.055	3	0.437	0.040	3
1948	0.426	0.026	6	0.427	0.021	3	0.425	0.031	3
1947	0.441	0.040	7	0.44	0.04	3	0.441	0.039	4
1946	0.389	0.064	7	0.377	0.065	3	0.402	0.064	4
1945	0.353	0.027	7	0.333	0.025	3	0.373	0.029	4
1944	0.356	0.063	7	0.353	0.075	3	0.358	0.05	4
1943	0.392	0.067	5						

DRTO *Siderastrea siderea* (continued)

1942	0.38	0.022	5						
1941	0.343	0.055	3						
1940	0.387	0.031	3						
1939	0.357	0.015	3						
1938	0.393	0.054	4						
1937	0.373	0.022	4						
1936	0.38	0.01	3						
1935	0.37	0.052	3						
1934	0.327	0.025	3						
1933	0.34	0.051	4						
1932	0.388	0.039	4						
1931	0.373	0.065	4						
1930	0.345	0.021	4						
1929	0.38	0.034	4						
1928	0.423	0.017	4						
1927	0.363	0.033	4						
1926	0.358	0.010	4						
1925	0.31	0.02	3						
1924	0.347	0.046	3						
1923	0.39	0.027	3						
1922	0.347	0.042	3						
1921	0.34	0.01	3						
1920	0.333	0.023	3						
1919	0.303	0.032	3						
1918	0.313	0.012	3						
1917	0.36	0.044	3						
1916	0.347	0.006	3						
1915	0.4	0.01	3						
1914	0.353	0.029	3						
1913	0.403	0.006	3						
1912	0.413	0.015	3						
1911	0.373	0.023	3						
1910	0.355	0.027	4						

DRTO *Siderastrea siderea* (continued)

1909	0.323	0.070	3						
1908	0.327	0.025	3						
1907	0.34	0.017	3						
1906	0.297	0.031	3						
1905	0.417	0.095	3						
1904	0.46	0.036	3						
1903	0.437	0.025	3						
1902	0.44	0.053	3						
1901	0.377	0.015	3						
1900	0.413	0.015	3						
1899	0.397	0.021	3						
1898	0.457	0.012	3						
1897	0.363	0.015	3						
1896	0.347	0.015	3						
1895	0.393	0.059	3						
1894	0.403	0.012	3						
1893	0.323	0.021	3						
1892	0.403	0.110	3						
1891	0.433	0.083	3						
1890	0.39	0.046	3						
1889	0.383	0.074	3						
Averagee	0.41	0.03		0.45	0.03		0.45	0.03	

DRTO *Diploria strigosa*

Year	C1	C1 Error (1σ)	C1 n	MK	MK Error (1σ)	MK n
2007	0.713	0.040	3	0.552	0.090	3
2006	0.832	0.063	4	0.556	0.023	3
2005	0.724	0.040	5	0.598	0.105	3
2004	0.666	0.064	5	0.556	0.030	3
2003	0.701	0.056	6	0.604	0.058	3
2002	0.743	0.086	6	0.574	0.037	3
2001	0.683	0.026	6	0.604	0.045	4
2000	0.777	0.089	6	0.567	0.039	5
1999	0.788	0.091	6	0.561	0.017	5
1998	0.685	0.063	6	0.548	0.040	5
1997	0.637	0.047	6	0.583	0.041	5
1996	0.753	0.036	6	0.657	0.086	5
1995	0.763	0.021	6	0.674	0.111	5
1994	0.758	0.104	6	0.659	0.083	4
1993	0.675	0.060	5	0.641	0.099	5
1992	0.663	0.020	5	0.582	0.071	5
1991	0.748	0.034	5	0.59	0.121	3
1990	0.792	0.042	5	0.604	0.102	3
1989	0.835	0.014	5	0.595	0.067	4
1988	0.742	0.088	5	0.582	0.037	3
1987	0.786	0.043	4	0.512	0.059	3
1986	0.726	0.064	4	0.564	0.057	3
1985	0.711	0.081	4	0.488	0.058	3
1984	0.729	0.039	4	0.561	0.017	3
1983	0.721	0.046	4	0.554	0.037	3
1982	0.772	0.033	4	0.513	0.027	3
1981	0.742	0.025	4	0.531	0.043	3
1980	0.83	0.02	3	0.607	0.092	3
1979	0.818	0.003	3	0.686	0.115	3
1978	0.645	0.012	4	0.747	0.027	3
1977	0.766	0.021	4	0.633	0.062	4
1976	0.688	0.026	3	0.614	0.042	4

DRTO *Diploria strigosa* (continued)

1975	0.725	0.074	3	0.594	0.084	4
1974	0.783	0.037	3	0.526	0.051	3
1973	0.757	0.040	3	0.552	0.051	3
1972	0.733	0.025	3			
1971	0.76	0.040	3			
1970	0.733	0.051	3			
1969	0.735	0.013	3			
1968	0.626	0.021	4			
1967	0.857	0.020	4			
1966	0.854	0.006	3			
1965	0.704	0.022	3			
1964	0.666	0.033	3			
1963	0.706	0.009	3			
1962	0.665	0.024	4			
1961	0.683	0.026	5			
1960	0.818	0.026	4			
1959	0.765	0.013	4			
1958	0.648	0.039	4			
1957	0.71	0.035	3			
1956	0.637	0.025	3			
1955	0.617	0.006	3			
1954	0.697	0.035	3			
Average	0.73	0.04		0.59	0.06	