Collection Methods and Descriptions of Coral Cores Extracted from Massive Corals in Dry Tortugas National Park, Florida, U.S.A.

By Michael S. Weinzierl, Christopher D. Reich, T. Don Hickey, Lucy A. Bartlett, and Ilsa B. Kuffner

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Cover photograph: A USGS scuba diver prepares to take a core sample from a 3-m tall *Orbicella faveolata* coral colony (“NK1”) in Dry Tortugas National Park, Florida. Photograph by Ilsa Kuffner, U.S. Geological Survey, May 2012.

Acknowledgments

The coral cores described in this study were collected under National Park Service (NPS) Dry Tortugas National Park scientific collection permit number DRTO-2012-SCI-0001 and are stored on loan from the NPS under accession number DRTO-00353 at the United States Geological Survey (USGS) St. Petersburg Coastal and Marine Science Center (SPCMSC). Additionally, the samples are cataloged in the SPCMSC Core Archive Database (http://olga.er.usgs.gov/coreviewer/). The collection expedition was funded by the USGS Coastal Marine Geology Program, with additional funding contributed by the USGS Climate and Land Use Research and Development Program. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government. We thank Kayla Nimmo, Tree Gottshall, and John Spade of the NPS, and Kyle Kelso of the USGS for help with locating and collecting the coral cores.

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)
yard (yd)	0.9144	meter (m)
	Area	
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square inch (in^2)	6.452	square centimeter (cm^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8.$$

Abbreviations

CE	common era
cm	centimeter
CT	computerized tomography
dpi	dots per inch
km	kilometer
m	meter
mAs	milli-Ampere-second
mm	millimeter
NPS	National Park Service
RNA	Research Natural Area
SPCMSC	St. Petersburg Coastal and Marine Science Center
USGS	United States Geological Survey

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Abstract

Cores from living coral colonies were collected from Dry Tortugas National Park, Florida, U.S.A., to obtain skeletal records of past coral growth and allow geochemical reconstruction of environmental variables during the corals' centuries-long lifespans. The samples were collected as part of the U.S. Geological Survey Coral Reef Ecosystems Studies project (http://coastal.er.usgs.gov/crest/) that provides science to assist resource managers tasked with the stewardship of coral reef resources. Three colonies each of the coral species *Orbicella faveolata* and *Siderastrea siderea* were collected in May 2012 using the methods described herein and as approved under National Park Service scientific collecting permit number DRTO-2012-SCI-0001 and are cataloged under accession number DRTO-353. These coral samples can be used to retroactively construct environmental parameters, including sea-surface temperature, by measuring the elemental composition of the coral skeleton. The cores described here, and others (see http://olga.er.usgs.gov/coreviewer/), can be requested, on loan, for scientific study. Photographic images for each coral in its ocean environment, the coral cores as curated and slabbed, and the X-rays of the slabs can be found in an associated U.S. Geological Survey Data Release.

Introduction

Stony corals (Order Scleractinia) are cnidarians that live in shallow, tropical seas around the world. These corals are sessile (live attached to the ocean bottom) and precipitate a calcium carbonate (aragonite) skeleton, slowly adding a new layer each year. Because stony corals form annual bands composed of high- and low-density band couplets in their skeletons (Knutson and others, 1972), and because they are sensitive to environmental factors (Hudson and others, 1976), they are useful for understanding shallow-water environmental conditions from the past. Corals provide insight into geological, climatic, and geochemical phenomena because their skeletons record local seawater chemistry during deposition (Corrège, 2006). Their characteristically large and enduring skeletons can record several centuries of change, enabling the reconstruction of environmental conditions during historical periods (Tierney and others, 2015) and during past geologic epochs (Flannery and Poore, 2013).

Florida is the only State in the continental United States with extensive shallow reefs near its coast. The most extensive living coral reefs occur adjacent to the island chain of the Florida Keys, the westernmost of which are the uninhabited and federally protected islands in Dry Tortugas National Park. The park includes several small islands, shallow banks, and vast coral reefs. The active reefs around the edge of the platform accumulate atop the existing antecedent high of the Key Largo limestone shelf (Shinn and others, 1977). The surrounding waters are influenced by the western Florida current—part of the loop-current system—which transports warm water from the Caribbean into the Gulf of Mexico and out through the Florida Straits (Shinn and others, 1977). This water transport and exchange creates surface waters around the Dry Tortugas that reflect water conditions in the tropical Atlantic, the Caribbean, and the Gulf of Mexico. Because of these water conditions and the Dry Tortugas being relatively far from freshwater influences and human activity, this area is an excellent location for open-ocean proxy calibration studies (DeLong and others, 2011; Flannery and Poore, 2013).

The growth records of the coral *Orbicella faveolata* (formerly part of the *Montastraea annularis* species complex) are the most extensively studied in the Atlantic Ocean (Hudson 1981; Hudson and others,1994), but recently, growth rates of *Siderastrea siderea* showed promise as proxies for environmental change (Saenger and others, 2009). Coral growth rates respond to many environmental variables, including water temperature (Shinn, 1966; Jokiel and Coles, 1977), hydrodynamics (Jokiel, 1978; Dennison and Barnes, 1988), and solar irradiance (Falkowski and others, 1990). The variables are often dynamic in shallow water environments along seasonal and shorter time scales, and growth rates are not uniform throughout the year (Kuffner and others, 2013). Therefore, geochemical proxies (Corrège, 2006) and skeletal growth rates (Lough and Cantin, 2014) can together yield a better understanding of past environmental conditions.

The first step in paleoreconstruction of environmental variables is obtaining growth records of the coral cores by slabbing, X-raying, and measuring linear extension (growth). After preliminary measurements and preparation, the coral can be analyzed for geochemical composition (elemental and isotopic). This report summarizes coral-core collections made during a May 2012 field expedition within the waters of Dry Tortugas National Park (fig. 1). The report provides a description of the collection sites and methods, preliminary processing, statistics for the cores and core sites, and preliminary growth rate data (linear extension) for six new coral cores.

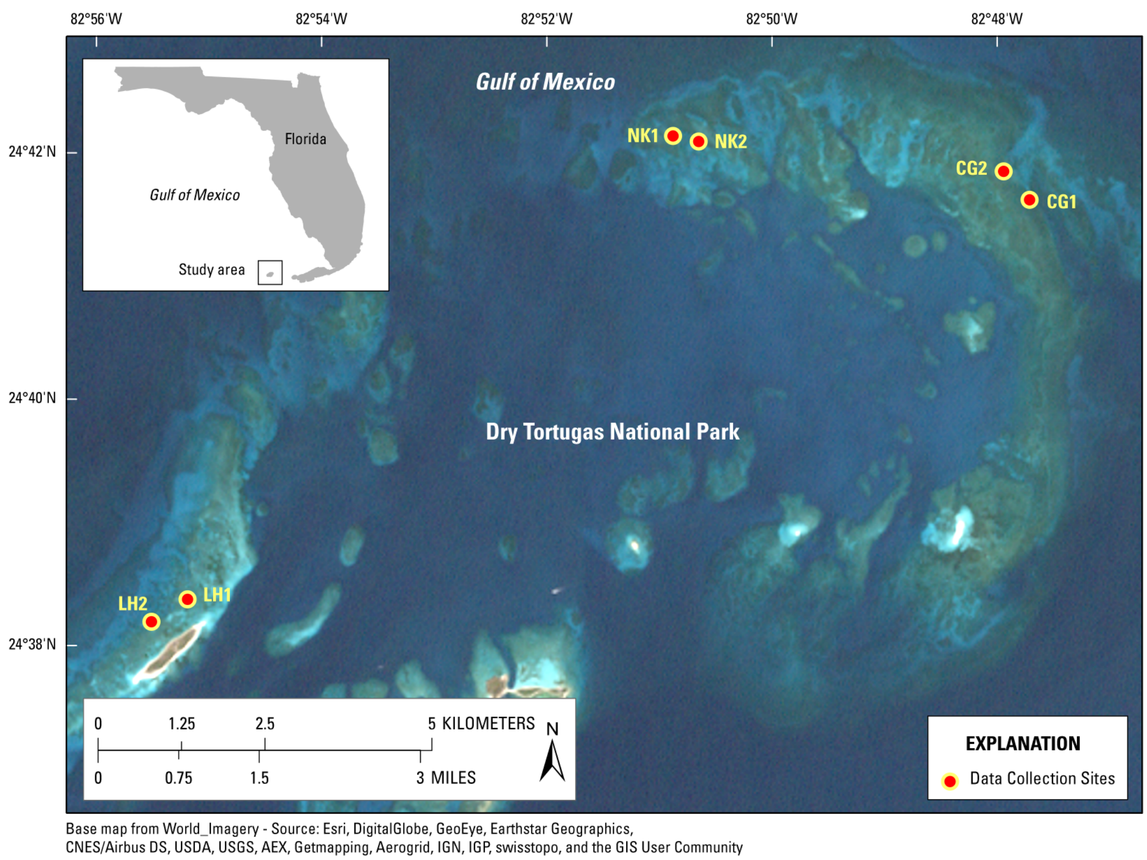

Figure 1. Map of the shallow banks of Dry Tortugas National Park, Florida. Data-collection sites (red circles) mark the locations where six coral cores were collected as part of this study. The inset shows the location of the study area in the southern Gulf of Mexico adjacent to the Florida peninsula.

Methods

Dry Tortugas National Park, established in 1992, occupies approximately 259 square kilometers (km^2) and is located 110 kilometers (km) west of Key West, Fla. In 2007, a 119 km^2, no-take "Research Natural Area" (RNA) was designated by the National Park Service (NPS) and the Florida Fish and Wildlife Conservation Commission in the northwest quadrant of the park (Hallac and Hunt, 2010).

After obtaining scientific research permit # DRTO-2012-SCI-0001 from the NPS, corals were collected during a field expedition in May 2012. Coral colonies were selected by searching areas known to have large colonies that represent centuries of growth. Two corals were chosen inside the borders of the RNA near Loggerhead Key (fig. 1; designated as LH1 and LH2), two corals were collected from north of North Key Harbor (NK1 and NK2), and two corals were collected from the "Coral Gardens" area of Pulaski Shoal (CG1 and CG2).

Previously established coral-coring methods (Reich and others, 2009; Hickey and others, 2013) were followed, including the use of a DL07652 Stanley hydraulic drill and drill head with a 4-inch-diameter core barrel, 24 inches in length, attached to a drill operated from the surface supply boat. A pilot hole was drilled into the coral surface with a ¼-inch starting bit to prevent the 4-inch bit from slipping sideways across the top of the coral head. To collect full coral cores, extension pieces were added after the primary core section was collected from the diamond-studded core barrel. The core barrel was reinserted into the drill hole several times to collect the full length of the core (fig. 2). For *Orbicella faveolata*, a plug of live coral was taken with the drill from the side of the colony to patch the main

Figure 2. U.S. Geological Survey scuba diver operating the hand-held hydraulic drill while coring an *Orbicella faveolata* coral (NK1) at the North Key site. Photograph credit: Ilsa B. Kuffner, U.S. Geological Survey

upward-facing hole (Hudson, 1983). This technique was successful for *O. faveolata* (fig. 3) but not for *Siderastrea siderea* because of the dense skeleton of the species. Instead, a precast concrete plug was inserted into the 4-inch holes remaining in the *S. siderea* heads, providing a suitably compatible substratum that can be overgrown by the coral. Following extraction, cores were placed on a table to dry before being wrapped in plastic and secured for travel.

Coral cores were sectioned along the primary growth axis into 4-millimeter-thick slabs using a lapidary saw with a carbide-tipped blade. Multiple (~3 to 4) slabs were taken from each coral-core section because corallite walls meander over time, and replicate slabs increase the chance of obtaining a continuous path for geochemical sampling. When necessary, the cores were angularly slabbed to follow the main axis of growth. The resulting slabs were cleaned in milli-Q water using a Branson Sonifer 450 sonication device and air dried before storage. None of the slabs were treated with bleach or oxidizing chemicals.

X-radiographs (X-rays) of each coral slab were taken at the U.S. Geological Survey (USGS) St. Petersburg Coastal and Marine Science Center (SPCMSC) in St. Petersburg, Fla. The coral slabs were placed on a phosphor plate and X-rayed at 55 kilovolts and 2.5 milli-Ampere-seconds (mAs). The distance between the plate and the X-ray source was 79 centimeters (cm). The plate was scanned on an iCR3600+ scanner at 254 dots per inch (dpi) resolution (10 pixels per millimeter (mm)), processed on iCRco, Inc., software, and adjusted for contrast with Adobe Photoshop.

Linear extension (mm per annual density-band couplet) was estimated by two separate observers using iSolution Capture version 3.1 image analysis software (IMTi-Solution, Inc., Vancouver, British Columbia, Canada) and averaged for each slab. The mean-growth rate reported for each coral-core section is an average of the mean estimates for each replicate slab (the number of slabs varying from 1 to 4), and the standard error is based on the corresponding number of slabs for each section.

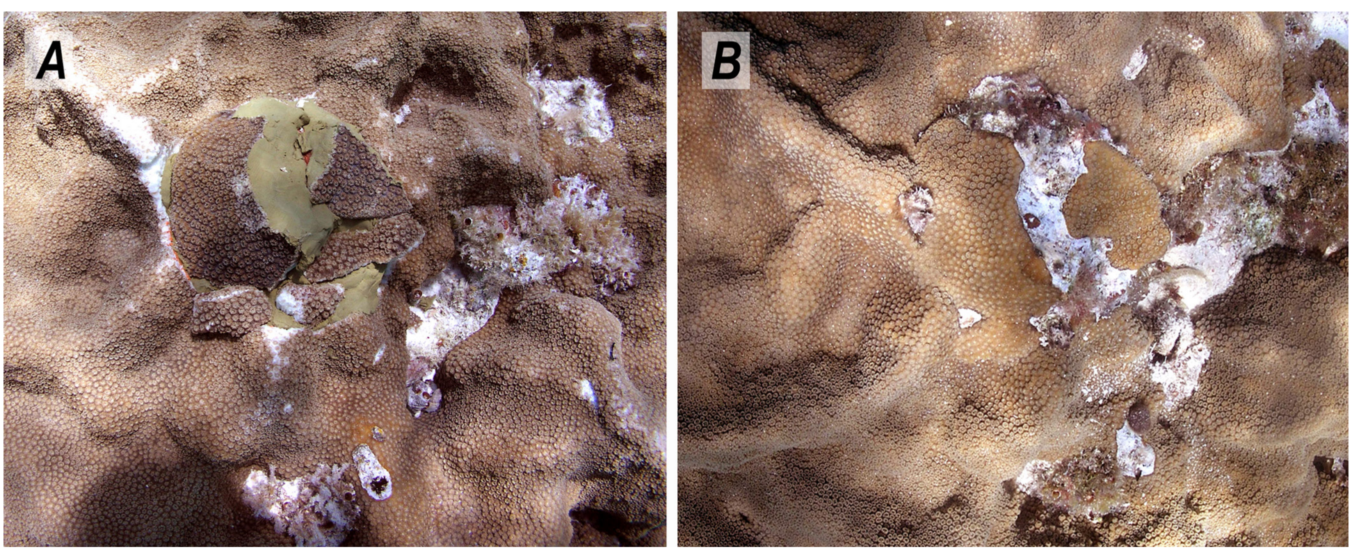

Figure 3. Coral LH1 (*Orbicella faveolata*) near Loggerhead Key (*A*) freshly cored with side-plug epoxied in place in May 2012, and (*B*) after 1 year of healing time in May 2013, demonstrating the success of the grafting method (note the fusion of live tissue between the transplanted plug and the surrounding hole). Photograph credits: Ilsa B. Kuffner, U.S. Geological Survey.

Results and Summary

The objective was to sample living coral colonies and obtain material to use in understanding recent (<200 years) changes in environmental and oceanographic conditions in the Dry Tortugas area. Three specimens each of *Orbicella faveolata* and *Siderastrea siderea* (table 1) were obtained. Several of the corals are estimated to be older than 100 years, dating back to the late 1800s. Photographs of individual coral colonies, resulting cores and slabs, and X-rays of slabs can be found in an associated USGS Data Release (Kuffner and others, 2016).

The 4-inch-diameter coral cores were slabbed along their major growth axes to obtain slabs for growth and geochemical analysis. The cores were not consumed by the slabbing process; vertical portions appropriate for computerized tomography (CT) scanning and other uses remained. The quality of the cores, with respect to their growth-axis angles, varied by species and core section. Table 2 summarizes the sections (designated by letter) for each core and the number of slabs per core section. The *Siderastrea siderea* cores (LH2, CG1, and CG2) had much straighter, consistent growth axes, resulting in high-quality slabs for geochemical and growth analysis. Growth rates (linear extension) for select sections of each core are also presented in table 2. Using the linear extension measurements and counting from the year of collection (2012), LH2 dates to approximately 1877 CE (common era); CG1 to 1900 CE; and CG2 to 1806 CE. Of note for core LH2 is a >20 cm length of subfossil *Orbicella faveolata* in core-section B, upon which the *S. siderea* colony grew.

The three *O. faveolata* (LH1, NK1, and NK2) cores did not produce easy-to-use slabs for geochemical or growth analysis. LH1 shows meandering of the main growth axes (see X-rays in Kuffner and others, 2016), but the use of multiple slabs per section enabled linear extension measurements, and analysis determined that this coral dates to approximately 1877 CE. The coral cores from NK1 and NK2 show extreme meandering of the main growth axis, necessitating slabbing on the bias, starting with the second section (B) down the core. This type of slabbing results in high numbers of slabs per core section (table 2) with considerable overlap in time for each slab. Sampling these cores for geochemistry would require advanced skill and resources, but based on the successful capture of the main growth axis by slabbing on the bias, it is possible.

Studies using these cores to discern paleoceanographic and paleoclimate conditions through elemental analysis of coral powders subsampled along the thecal walls of the growth axis of each coral are underway (for example, Flannery and others, in press). The cores belong to the NPS and are on loan to the USGS at the SPCMSC in St. Petersburg, Fla., under NPS accession number DRTO-00353. Permission to borrow the samples for scientific investigation can be requested from the NPS and facilitated by the USGS.

Table 1. Information for six coral cores from Dry Tortugas National Park, Florida, collected May 10–13, 2012. Water depth reported is the ocean floor. To calculate depth at colony surface, subtract the length of the core.

Core Name	Location	Coral Species	Date Collected	Latitude (N°)	Longitude (W°)	Water Depth (m)	Core Length (cm)
LH1	Near Loggerhead Key	*Orbicella faveolata*	5/10/2012	24.640	-82.919	3	149
LH2	Near Loggerhead Key	*Siderastrea siderea*	5/11/2012	24.637	-82.924	3.6	85
CG1	Near Pulaski Shoal	*Siderastrea siderea*	5/11/2012	24.695	-82.795	4.2	58
CG2	Near Pulaski Shoal	*Siderastrea siderea*	5/13/2012	24.699	-82.799	3	93
NK1	Near North Key Harbor	*Orbicella favealata*	5/12/2012	24.703	-82.848	3.9	302
NK2	Near North Key Harbor	*Orbicella faveolata*	5/13/2012	24.703	-82.844	4.5	274

Table 2. Information for six coral cores from Dry Tortugas National Park, Florida, collected May 10–13, 2012. Sections are the contents of each core-barrel extracted from the colony; the topmost section is labeled “A,” the section beneath it is labeled “B,” and the labeling process continues in alphabetical order. The number of slabs shows how many replicate slabs were cut from each core section. Linear extension estimates were made from X-ray images of the slabs (see the Methods section for details). N/A = not applicable.

Coral Core	Section	Total Slabs	Core-section Length (cm)	No. of Slabs X-rayed	Linear Extension (mean mm year $^{-1}$ ± SE)
LH1	A	4	52	4	8.2 ± 0.2
	B	4	55	4	9.4 ± 0.2
	C	4	42	4	10.9 ± 0.3
LH2	A	4	56	4	4.2 ± 0.1
	B	0	29	N/A	N/A
CG1	A	4	52	4	4.4 ± 0.1
	B	0	6	N/A	N/A
CG2	A	3	53	2	4.3
	B	3	40	1	N/A
NK1	A	4	28	1	11.0
	B	4	53	0	N/A
	C	25	56	0	N/A
	D	12	45	0	N/A
	E	10	34	0	N/A
	F	0	13	N/A	N/A
	G	1	17	0	N/A
	H	12	56	0	N/A
NK2	A	4	55	1	8.4
	B	4	48	0	N/A
	C	3	50	0	N/A
	D	0	55	N/A	N/A
	E	0	39	N/A	N/A
	F	0	27	N/A	N/A

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