

Photogrammetric Assessment of 1733 *San Pedro* Underwater Archaeological Preserve and 1733 *San Felipe* Shipwreck Sites following Hurricane Irma



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I. Acknowledgements

This project and report were made possible through the collaborative efforts of many people and institutions. Thanks to the Indiana University (IU) summer 2018 field study project team members: Emma DeLillo, Nicholas Maguire, Rachel McIntosh, Jacob Parker, Rocky Ramsey, and Hanna Winston. The IU project team thanks the Florida Division of Historical Resources, the Florida Division of Recreation and Parks, and the NOAA Florida Keys National Marine Sanctuary (FKNMS) for providing research permits. We specifically acknowledge Matthew Lawrence, John Katchenago, and Brenda Altmeier for their continued support of our research efforts and their own efforts to protect Florida's Underwater Cultural Heritage as part of the FKNMS team. Additional thanks to Rob Blesser and Quiescence Diving Services for logistical support and use of the Coral Sea for the Research Vessel, and Matthew Maus, who authored IU's 2015 report *Application of Photogrammetry for Assessment and Monitoring of the 1733 San Pedro Underwater Archaeological Preserve*.

II. Introduction

Both the *San Pedro* and the *San Felipe* were travelling with the Captain-General Rodrigo de Torres' Spanish Plate Fleet, making their way from Havana Harbor back to Spain in July of 1733. While passing through the Florida Keys, they were caught in a hurricane which resulted in the loss of the *San Pedro* and the *San Felipe*, along with most of the fleet. In 1988, Indiana University (IU) assisted the State of Florida in the survey and inspection of the 1733 *San Pedro* and *San Felipe* shipwrecks with the goal of selecting a candidate for the creation of an underwater archaeological preserve. In April 1989, the *San Pedro* Underwater Archaeological Preserve State Park was opened to the public, and IU has continued to conduct periodic assessments of the preserve to provide archaeological and biological monitoring information to resource managers.

The *San Pedro* and *San Felipe* continue to support diverse assemblages of marine organisms that are representative of one of Florida's oldest artificial reefs. Subsequently, IU has over 30 years of data collected through monitoring efforts of both shipwrecks. This report uses these materials to make comparisons and analyze the current state of the sites. Following Hurricane Irma's impact on the Florida Keys in September of 2017, IU returned to the *San Pedro* and *San Felipe* to record observations and assess the condition of the sites. Additionally, structure-from-motion, computer vision photogrammetry was used to produce orthomosaic site plans and three-dimensional models which have been used to analyze changes in the sites and provide a baseline monitoring reference for future work

III. Site Information

San Pedro Underwater Archaeological Preserve

General Location: 1.25 nm south of Indian Key

GPS Location: 24° 51.802' N 80° 40.795' W

Background: Prior to establishment as a state park in 1989, the site was heavily impacted by salvage efforts that reduces the original ballast pile into a low-profile scatter of disarticulated ballast stones and a small number of galley bricks. Marine life is typical of an inshore patch reef community surrounded by a halo of sand resulting from invertebrate grazing on the sea grass around the ballast scatter. Initial park enhancement included consolidation of scattered ballast, placement of an 18th century anchor with zinc anode, seven museum-quality replica cement cannons, an interpretive plaque, and installation of six anchor blocks for a historic marker buoy and mooring buoys.

San Felipe

General Location: 1 nm south of Lower Matecumbe Key

GPS Location: 24° 50.761'N 80° 42.850'W

Background: While the site experienced salvage through the years, efforts were less detrimental than those on the *San Pedro*. This left the ballast pile mostly intact, with articulated ballast throughout the center of the site and disarticulated ballast surrounding. This articulated ballast has proven a suitable substrate for some coral species, as growth is more prevalent here than at the *San Pedro*. The site was nominated to the National Register of Historic Places in 1994.

IV. Diving Conditions

San Pedro Underwater Archaeological Preserve

Depth: 5.5 m (18ft)

Bottom Type: Riverine ballast, sand, seagrass

Accessibility: Only accessible by boat. Five mooring buoys are on site.

Surface Conditions: 0-1 ft.

Wind: 4-8 kn.

Current: none

Visibility: 20 ft.

San Felipe

Depth: 5.8 m (19ft)

Bottom Type: Riverine ballast, sand, seagrass

Accessibility: Only accessible by boat. Visitors can anchor in seabed away from corals or seagrass.

Surface Conditions: 0-1 ft.

Wind: 4-8 kn.

Current: none

Visibility: 20 ft.

V. Dive Team

Name	Project Title	Role(s)
Beeker, Charles, PhD	Principle Investigator	Archaeology
Haskell, Samuel MS	Diving Safety Officer	Safety, Archaeology, Photogrammetry
Hawley, Kirsten	Research Associate	Archaeology
Johnson, Claudia, PhD	Coral Specialist, Geologist	Coral Identification
Ruff, William, PhD	Biologist	Coral Identification
Lawrence, Matthew MA	NOAA Archaeologist	Archaeology, Photography
Galloway, Tori	Research Assistant, NOAA Intern	Archaeology, Photogrammetry

VI. Activities

Field Documentation Dates: 1, 5-6 June 2018; 9-10 July 2018

Research Vessels: NOAA Sea Vee (Sanctuary Vessel R 3002), Coral Sea (44' Harkers Cabin Cruiser, Documented Vessel DO 522399)

Dives and Bottom Time: Indiana University divers completed a total of 26 dives on the *San Pedro* Underwater Archaeological Preserve for a total bottom time of 19 hours and 15 minutes. IU divers completed a total of 27 dives on the *San Felipe* for a total bottom time of 20 hours and 11 minutes.

On-Site Activity: Researchers used SCUBA to conduct visual and photographic documentation of the cultural resources, associated biology, enhancement features, and buoy system within the 1733 *San Pedro* Underwater Archaeological Preserve and the 1733 *San Felipe*. A major component of this fieldwork was the generation of multiple photogrammetric models of the shipwrecks. Additionally, cannon 5, a replica cannon on the 1733 *San Pedro* Underwater Archaeological Preserve, which had been buried since 2004, was uncovered by recent hurricane activity and moved near other replica cannons on the site. This work resulted in no impact to either shipwreck. Researchers did not conduct excavation, specimen or artifact collection, or remote sensing.

VII. Photogrammetric Methodology

Overview: The photogrammetric methodology employed in this assessment was designed to be inexpensive and quick, while simultaneously providing high quality, detailed imagery and volumetric data. The fieldwork component of this process is efficient enough to permit imagery collection from multiple sites in a single day. As such, it would be feasible and beneficial to employ this photogrammetric monitoring technique regularly as part of a rapid assessment protocol to closely track changes in submerged cultural and biological resources with a very high degree of accuracy and detailed resolution. Therefore, the photogrammetric results from this project should be considered for use as a continued baseline for monitoring the *San Pedro* Underwater Archaeological Preserve and the *San Felipe*. As an added benefit, the accessible and detailed photogrammetric models produced by this process have excellent potential as tools for public outreach and education, and for comparing site changes pre and post-hurricane.

Data-Collection Methodology: Divers using open circuit SCUBA took all photogrammetric imagery in this report. Prior to starting photo transects, at least two coded targets should be deployed at opposite ends of the site. For convenience, a meter bar with two coded targets can be deployed, with a marked end pointing toward north for easy orientation. Once targets were deployed, the diver swam transects over the area while taking photos on two-second intervals (using the time lapse function of the camera). Time lapse settings allow the diver to focus on making straight transects and getting an ideal amount of overlap (60% side, 80% forward) to guarantee photo alignment. During transects, the diver should swim at a slow, constant speed. Each model was created using images taken in under a 60-minute dive.

Photogrammetry Workflow Summary: Following the dive, the imagery data was reviewed and images were processed in Adobe Lightroom for white balance, sharpness, and color enhancement. Then, Agisoft Photoscan was used to align the images, build a sparse point cloud and dense point cloud, generate a mesh, and apply texture. Note that Photoscan automatically detects and corrects GoPro lens distortion, and the algorithm filters out most mobile subjects such as fish or other moving organisms. Photogrammetric processing in Photoscan is both memory and time intensive and can take one or more days of computer time to run. Following completion, the models were decimated and cropped for uploading to Sketchfab, which makes the models more easily available for remote access from any computer. All source images and photogrammetric models will be provided to NOAA.

VIII. San Pedro¹ Preserve Infrastructure Assessment

Plaque: Bronze interpretive plaque and limestone monument are present and in good condition (Image 1). The plaque is difficult to read due to algae growth; recommend cleaning. The Indiana limestone monument was initially placed in the sand patch south of the site, which results in the necessity to periodically lift the entire monument or move sand from the front of the monument in order to read the full listing of sponsors.

Historic Marker Buoy: The Historic Marker (HM) Buoy is present and in good condition. The HM Buoy is currently located north of the shipwreck, which may make it difficult for novice divers and snorkelers to locate the site in low visibility conditions. We recommend that the buoy be relocated to the sand area near the plaque to facilitate site access by divers.

Mooring Buoys: Five Mooring buoys present and in good condition.

Buoy Anchor Blocks: Buoy anchor blocks are present and in good condition. Sand movement due to Hurricane Irma has uncovered blocks which were previously sinking in sand (blocks 3 and 4 in 2015). We recommend monitoring of blocks sinking in the future and extensions added to eye-bolts before they are buried by sand.

IX. Cultural Resources Assessment

San Pedro Underwater Archaeological Preserve

Ballast: Riverine ballast stones account for the most significant visible feature of the 1733 *San Pedro* shipwreck. Due to severe salvage disturbance before park establishment, the stones are loose and disarticulated. Based on the photogrammetric model produced by this project², the ballast pile covers an area of approximately 634.75 m² and has a volume of 53.50 m³. Comparison of 2015 and 2018 photogrammetric site plans reveal significant ballast stone movement by Hurricane Irma (p. 13-14).

Anchor: The 18th-century anchor that IU placed on the site in 1989 is present and in good condition (Image 2). A zinc anode is attached to the shank to inhibit corrosion. Consequently, the anchor surface is mostly absent of benthic organisms such as coral colonies or sponges (possibly due to the anode inhibiting accretion of calcium carbonate). The anchor is resting on its ring, which likely puts excessive pressure on the ring and shank; we recommend placing blocks or some other form of support underneath the shank to relieve stress and weight from the anchor ring.

Replica Cannons: IU placed museum-quality replica cement cannons on the site in 1989, which were manufactured by the State of Florida using a fiberglass mold of a 1733 cast-iron cannon. To

¹ Note that the *San Felipe* is not a developed park and therefor does not have any established infrastructure

² *San Pedro* photogrammetric model had an error of 0.02m

facilitate periodic monitoring the replica cannons were assigned numbers 1—7, starting clockwise from the crown of the 18th-century anchor. In 2003, Replica Cannon 5 was reported by IU to be missing (presumably buried in the sand) and Cannon 4 was relocated onto the ballast stones between Cannons 6 and 7. Following Hurricane Irma, during the 2018 assessment, all cannons were present and in good condition, including the previously buried Cannon 5 (Images 3-4). Several cannons were moved during Hurricane Irma, as detailed in the table below. Following initial assessment, Cannon 5 was lifted by IU divers and moved back onto the site, between Cannons 3 and 6 (Image 5).

Cannon Movement by Hurricane Irma³

Cannon	Movement by Hurricane Irma
C1	Shifted orientation
C2	No notable movement
C3	Moved 3m NW toward C2
C4	No notable movement; some sand coverage
C5	Relocated
C6	Moved 4m NW toward C4
C7	No notable movement

The similarity of the cement substrate to calcium carbonate seems to promote coral recruitment. Previously, IU has documented over 400 recruitment corals 1.5cm or greater on the replica cannons. However, due to shifting sands, wave action, and cannon and sand movement due to Hurricane Irma, this number is no longer consistent. Some colonies have survived and grown larger, while others are dead or degraded as a result of sedimentation.

San Felipe

Ballast: Riverine ballast stones account for the most visible feature on the shipwreck. Although the majority of the ballast is disarticulated due to previous salvage, there is approximately 6.5 m³ of articulated ballast stones on the southeast side of the site (Image 9). The overall ballast, articulated and disarticulated, and associated coral growth cover an area of about 551.85 m². Measurements are based on the photogrammetric model produced by this project⁴.

Wood: Previously buried wood has been uncovered, presumably by Hurricane Irma, on the southeast side of the ballast pile (Images 10-12). Recommend reburial of exposed wood.

³ See changes in photogrammetric site plans from 2015 to 2018 (p.13-14)

⁴ *San Felipe* photogrammetric model had an error of 0.02m

X. Biological Resources Assessment

San Pedro Underwater Archaeological Preserve

Observations: The *San Pedro* is a successful Marine Protected Area that continues to support a diverse assemblage of marine organisms typical for an inshore patch reef community representative of one of Florida's oldest artificial reefs. During the project, numerous schooling fish and invertebrates were observed on the site, as well as hundreds of lobsters (Image 7) inhabiting the available rugose substrate of the ballast scatter. Previous IU reports indicate other organisms regularly visit the site, such as sea turtles and nocturnal shrimp and basket starfish. One invasive lionfish was spotted on the site (Image 6). Because the ballast is largely disarticulated, the unconsolidated substrate of the stones is not conducive to long-term coral stability and growth (see comparative photographs, p.17-18). Ballast stones and replica cannons continue to provide substrate for numerous coral and sponge recruits, however long-term growth appears to be regularly disrupted by sedimentation due to burial or movement by hurricanes and other strong weather patterns.

The present biological condition was compared to that documented in a 1988 IU report to indicate the overall health of the site. About 61% of the total segmented worms, crustacea, echinoidea, and cnidarians identified in 1988 were seen again along with an addition of four new invertebrate species. Considering that a majority of the invertebrates were seen again in a dive time of only 1 hour and 58 minutes, the percentage reflects that this marine ecosystem is in good overall health. The establishment of the area into a State Park is most likely what has reduced the level of disturbance as it is illegal to salvage the wreck for treasure. Overall, the abundance of invertebrates along with vertebrates indicates that the reef is currently in a healthy state. As long as disturbance continues to stay limited, this inshore patch reef community will likely be around for the future generations to appreciate.

Hazards to Biology: Illegal fishing and lobster trapping.

San Felipe

Observations: The *San Felipe* supports a diverse assemblage of marine organisms typical for an inshore patch reef community (Image 13). During the project, numerous schooling fish and invertebrates were observed on the site. Because the ballast is largely disarticulated, the unconsolidated substrate of the stones is not conducive to long-term coral stability and growth (see comparative photographs, p.17-18). Ballast stones continue to provide substrate for numerous coral and sponge recruits, however long-term growth appears to be regularly disrupted by sedimentation due to burial or movement by hurricanes and other strong weather patterns.

Hazards to Biology: Illegal fishing and lobster trapping; anchoring vessels near or on site.

XI. Biological Resources Inventory

San Pedro Underwater Archaeological Preserve⁵

Fish

- | | |
|--|---|
| 1. Sergeant Major (<i>Abudefduf saxatilis</i>) | 18. Spotted Moray (<i>Gymnothorax moringa</i>) |
| 2. Roughhead Blenny (<i>Acanthemblemaria aspera</i>) | 19. French Grunt (<i>Haemulon flavolineatum</i>) |
| 3. Scrawled Cowfish (<i>Acanthemblemaria quadricornis</i>) | 20. Bluestriped Grunt (<i>Haemulon sciurus</i>) |
| 4. Doctorfish (<i>Acanthurus chirurgus</i>) | 21. Yellowhead Wrasse (<i>Halichoeres garnoti</i>) |
| 5. Blue Tang (<i>Acanthurus coeruleus</i>) | 22. Queen Angel (<i>Holacanthus ciliaris</i>) |
| 6. Porkfish (<i>Anisotrmmus coeruleus</i>) | 23. Rock Beauty (<i>Holacanthus tricolor</i>) |
| 7. Gray Triggerfish (<i>Balistes capriscus</i>) | 24. Hogfish (<i>Lachnolaimus maximus</i>) |
| 8. Sharpnose Puffer (<i>Canthigaster rostrate</i>) | 25. Smooth Trunkfish (<i>Lactophrys triqueter</i>) |
| 9. Four Eye Butterfly (<i>Chaetodon capistratus</i>) | 26. Gray Snapper (<i>Lutjanus griseus</i>) |
| 10. Spotfin Butterfly (<i>Chaetodon ocellatus</i>) | 27. High Hat (<i>Pareques acuminatus</i>) |
| 11. Banded Butterfly (<i>Chaetodon striatus</i>) | 28. Gray Angel (<i>Pomacanthus arcuatus</i>) |
| 12. Bridled Goby (<i>Coryphopterus glaucofraenum</i>) | 29. French Angel (<i>Pomacanthus paru</i>) |
| 13. Porcupine Fish (<i>Diodon hystrix</i>) | 30. Harlequin Bass (<i>Serranus tigrinus</i>) |
| 14. Neon Goby (<i>Elacatinus oceanops</i>) | 31. Spotlight Parrotfish (<i>Sparisoma viride</i>) |
| 15. Red Grouper (<i>Epinephelus morio</i>) | 32. Checkered Puffer (<i>Sphoeroides testudineus</i>) |
| 16. Green Moray (<i>Gymnothorax funebris</i>) | 33. Great Barracuda (<i>Sphyraena barracuda</i>) |
| 17. Goldentail Moray (<i>Gymnothorax miliaris</i>) (2015) | 34. Yellow Stingray (<i>Urobatis jamaicensis</i>) |

Invertebrates (excluding corals and sponges)

Segmented Worms

1. Variegated Feather Duster (*Bispira variegata*) (2015)
2. Spotted Feather Duster (*Branchioma nigromaculata*)
3. Feather Duster (*Sabellid sp.*)
4. Christmas Tree Worm (*Spirobranchus giganteus*) (2015)
5. Horned Christmas Tree Worm (*Spirobranchus grandis*)

Crustacea

1. Star-Eyed Hermit Crab (*Datdanus venosus*)
2. Channel Clinging Crab (*Mithrax spinosissimus*) (2015)
3. Spiny Lobster (*Panulirus argus*)

⁵ This listing includes specimen observed in 2018 and 2015. If the species was not observed in 2018, it is denoted by (2015). No biological inventory was conducted on the *San Felipe*.

4. Pederson's Cleaning Shrimp (*Periclimenenes pedersoni*)
5. Oscellate Swimming Crab (*Portunus sebae*)
6. Banded Coral Shrimp (*Stenopus hispidus*)
7. Arrow Crab (*Stenorhynchus seticornis*)

Echinoidea

1. Reef urchin (*Echinometra viridis*)

Cnidarians

1. Corkscrew Anemone (*Bartholomea annulata*)
2. Moon Jellyfish (*Aurelia aurita*)

Asteroidea

1. Giant Basket Star (*Astrophyton muricatum*) (2015)
2. Brittle Star (*Ophiuroidea sp.*)

Mollusca

- | | |
|--|--|
| 1. Long-Spined Star Shell (<i>Astraea Americana</i>) | 8. Measled Cowrie (<i>Cypraea zebra</i>) |
| 2. Lightening Whelk (<i>Busycon contrarium</i>) | 9. Banded Tulip (<i>Fasciolaria hunteria</i>) |
| 3. <i>Calthalotia strigata</i> | 10. Rough Lima (<i>Lima scabra</i>) |
| 4. Florida Cerith (<i>Cerithium atratum</i>) | 11. Atlantic Deer Cowrie (<i>Macrocypraea cervus</i>) (2015) |
| 5. Sozon's Cone (<i>Conus delesserti</i>) | 12. Ponderous Ark (<i>Noetia ponderosa</i>) |
| 6. Alphabet Cone (<i>Conus spurius</i>) | 13. White Atlantic Semele (<i>Semele proficua</i>) |
| 7. Atlantic Hairy Triton (<i>Cymatium aquatile</i>) | 14. Cockle (<i>Trachycardium sp.</i>) |

Reptiles

1. Loggerhead Turtle (*Caretta caretta*) (2015)
2. Hawksbill Turtle (*Eretmochelys imbricate*) (2015)

XII. Recommendations

San Pedro Underwater Archaeological Preserve

- Conduct periodic photogrammetric monitoring of the *San Pedro* Underwater Archaeological Preserve as part of regular rapid assessment protocol in comparison to the 2015 baseline.
- Monitor buoy system anchor blocks to ensure eye-bolts are not completely buried in sand. Extend as necessary.
- Conduct regular monitoring of the replica cannons. Lift and position cannons as necessary to prevent sedimentation adversely affecting coral recruits.
- Move the Historic Marker Buoy with appropriate anchor system to the sand area in close proximity to the plaque in order to provide safe and easy descent into the site for divers.
- Conduct periodic maintenance and cleaning of the site, including removing any remnant lobster traps (Image 8) and cleaning the dedication plaques.
- Lift anchor and place blocks or other support system underneath shank to relieve weight from anchor ring.
- Incorporate photogrammetry into the rapid assessment protocol and establish photogrammetric baselines for other sites.

San Felipe

- Conduct periodic photogrammetric monitoring of the *San Felipe* as part of regular rapid assessment protocol in comparison to the 2018 baseline.
- Assess and rebury the exposed wood on the southeast side of the site.
- Incorporate photogrammetry into the rapid assessment protocol and establish photogrammetric baselines for other sites.

XIII. Conclusions

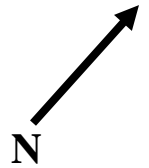
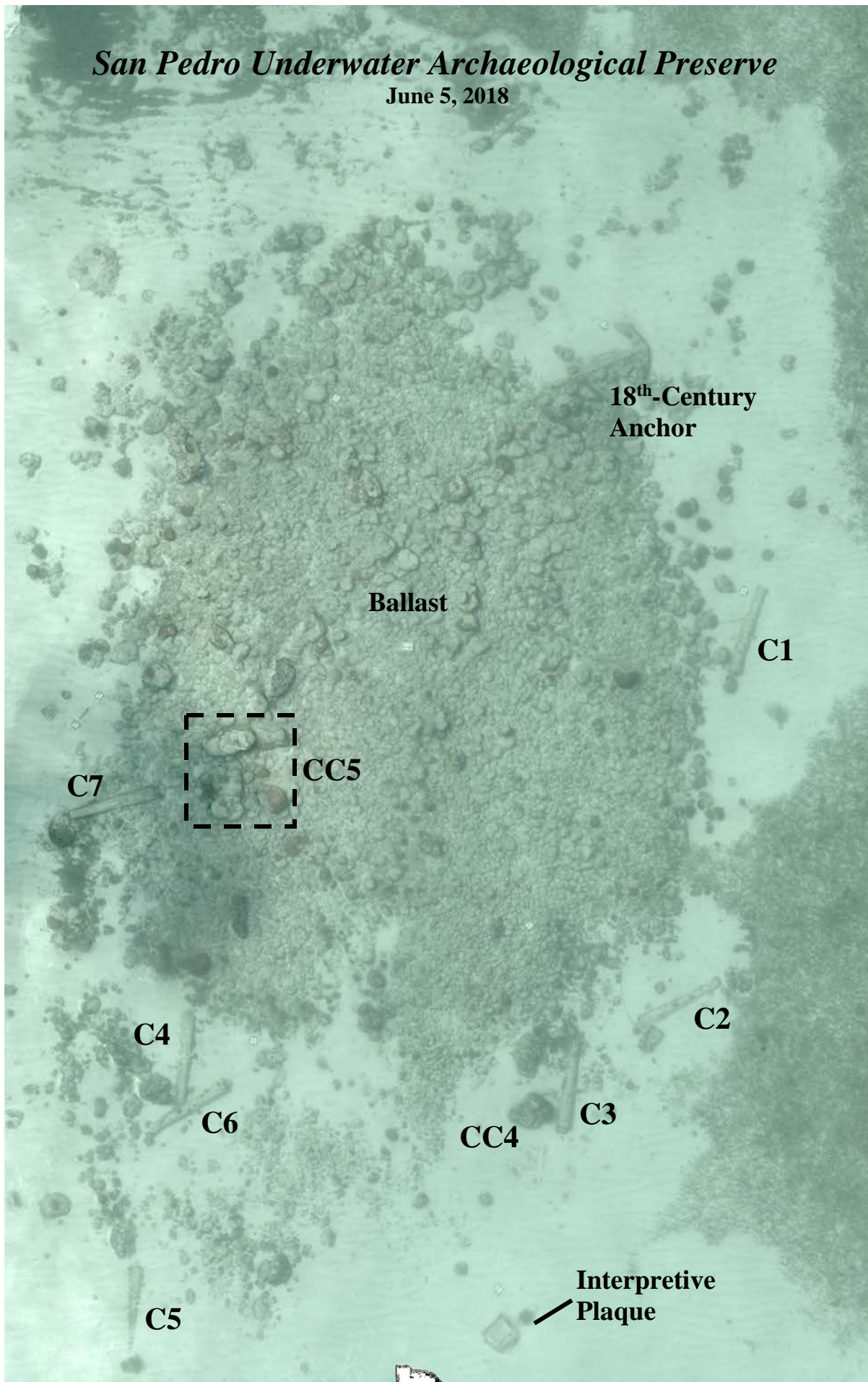
The impacts of Hurricane Irma can clearly be seen on both the *San Pedro* and *San Felipe*. Several cannons were moved, and significant sand movement on the *San Pedro* revealed the previously lost Cannon 5 and uncovered several of the previously buried buoy blocks. Hurricane impacts on the *San Felipe* are most obviously visible on the southeast side of the site, where a significant number of wood pieces were uncovered and are now disarticulated on the surface. This wood should be reburied as soon as possible to avoid any degradation of the archaeological resources. Despite these disturbances, overall the two sites appear stable.

As a State Park, that *San Pedro* Underwater Archaeological Preserve remains a successful Marine Protected Area, as evidenced by the high numbers of visitors to the site as witnessed by IU during their time there and the abundance of marine life on the artificial reef. Although neither site appears to be sustaining long-term large coral growth, the abundance of invertebrates and fish are evident of successful inshore patch reef communities. The *San Pedro* and *San Felipe* are prime examples of Marine Protected Areas conserving both underwater cultural heritage and associated marine ecosystems while promoting sustainable tourism.

XIV. Photogrammetric Site Plans

San Pedro Underwater Archaeological Preserve

June 5, 2018



3 meters
*.02m error

Legend:

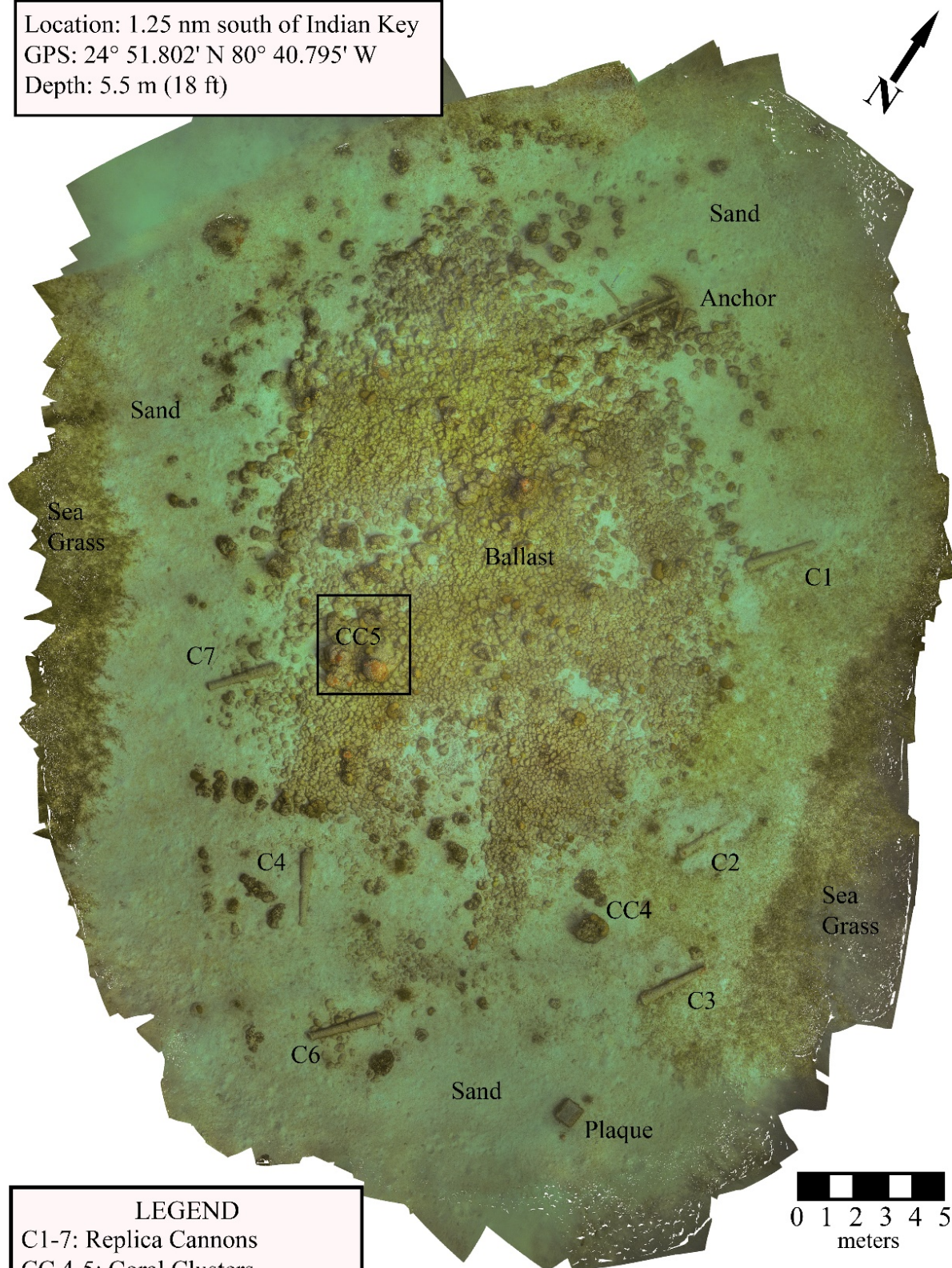
C1-7: Cannons

CC4-5: Coral Clusters

San Pedro Underwater Archaeological Preserve

Photogrammetric Site Plan, July 2015

Location: 1.25 nm south of Indian Key
GPS: 24° 51.802' N 80° 40.795' W
Depth: 5.5 m (18 ft)



LEGEND

C1-7: Replica Cannons

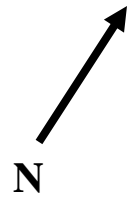
CC 4-5: Coral Clusters

□ : 2003 Coral Restoration Site

San Felipe

June 6, 2018

Ballast



3 meters

*.02m error

Coral 7



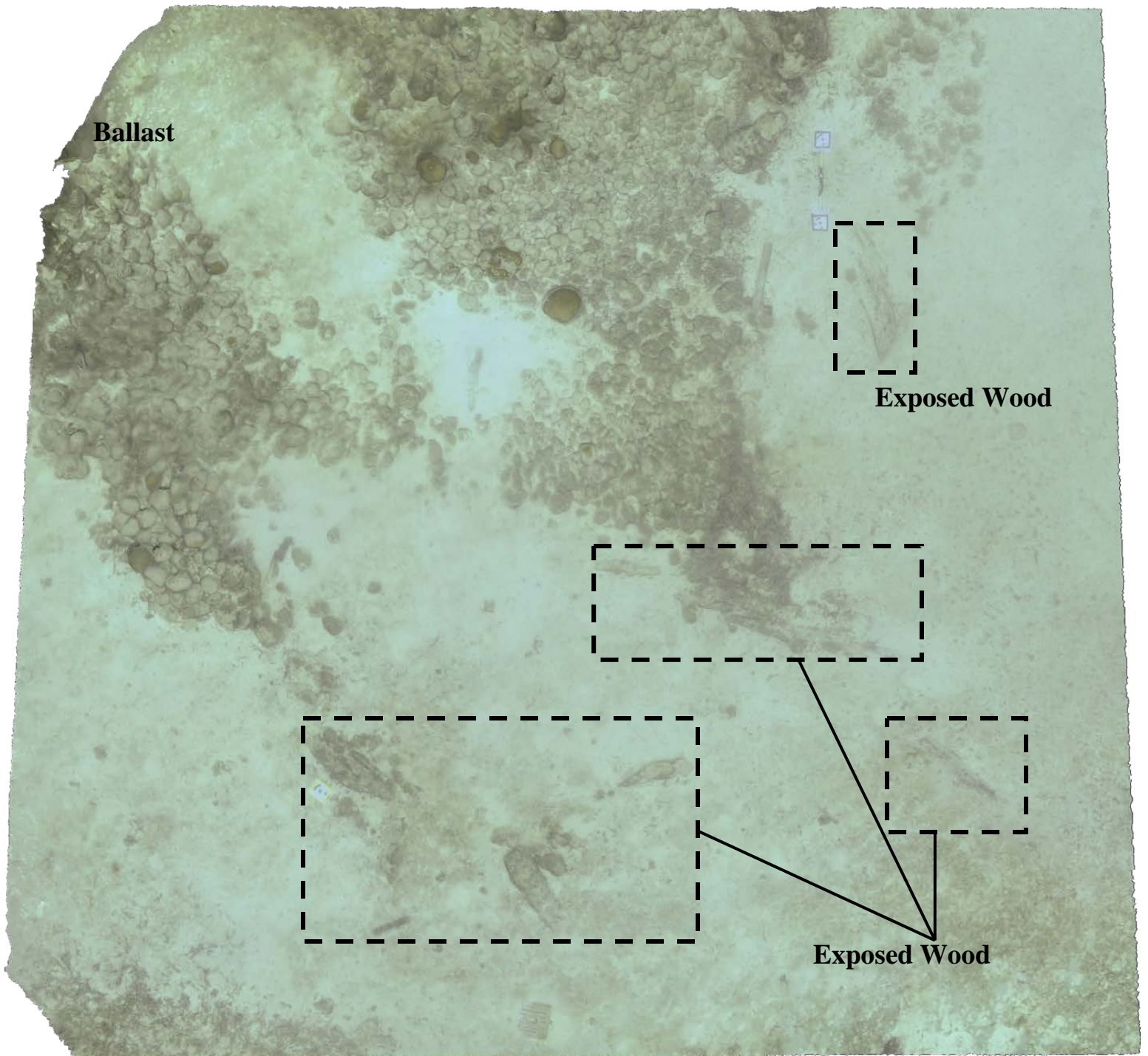
Articulated
Ballast



Ballast

Coral 4

San Felipe
(Southeast side of site)
July 10, 2018



2 meters
*.02m error

XV. Comparative Photographs
San Pedro Underwater Archaeological Preserve

Coral Cluster 4



Coral Cluster 4 in 1988



Coral Cluster 4 in 2018

Coral Cluster 5



Large coral head later used in Coral Cluster 5
1988



Coral head being moved after upturning
2000



Coral Cluster 5 after being cemented in 2003

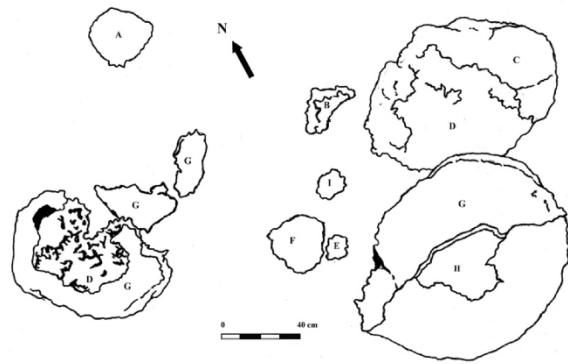


Illustration of Coral Cluster 5 in 2003



Coral Cluster 5, highly degraded, in 2018

San Felipe

Coral 2 (*Siderastrea siderea*)

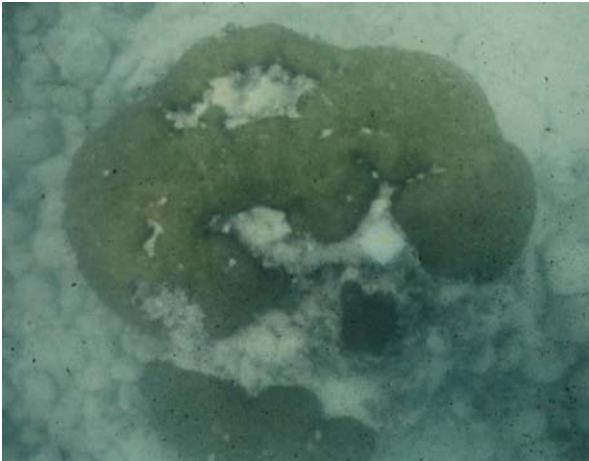


Coral 2 in 1992



Coral 2 in 2018

Coral 7 (*Siderastrea siderea*)



Coral 7 in 1992



Coral 7 in 2018

XVI. Images

San Pedro Underwater Archaeological Preserve



Image 1: *San Pedro* Underwater Archaeological Preserve Interpretive Plaque



Image 2: 18th-Century Anchor, placed on the *San Pedro* site in 1989



Image 3: Cannons 4 and 6, pushed together by Hurricane Irma



Image 4: Cannon 5, relocated in the sand to the South of the site



Image 5: IU divers lift Cannon 5 to replace it on site



Image 6: Invasive lionfish spotted on site



Image 7: One of the many lobsters living on the *San Pedro*



Image 8: Old lobster trap and associated rope on site

San Felipe



Image 9: Articulated and disarticulated ballast of the *San Felipe*



Image 10: C. Beeker documents exposed wood on the *San Felipe*

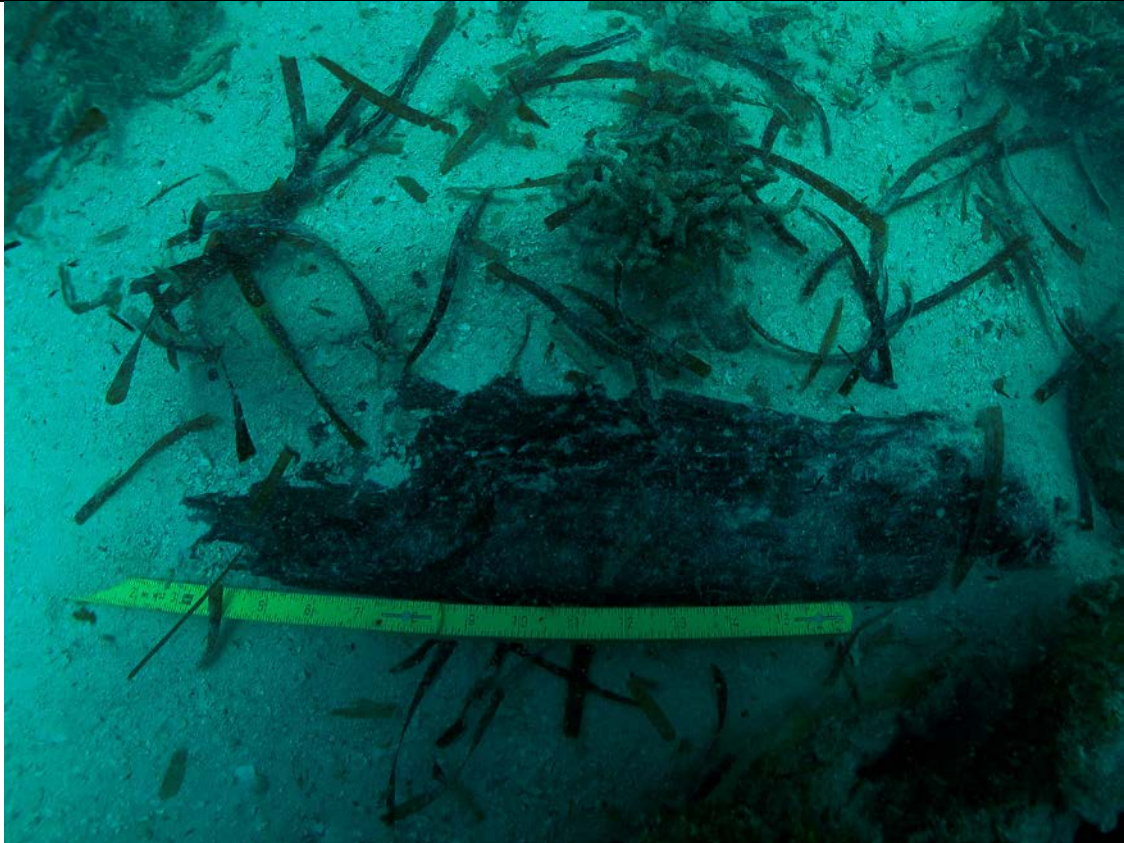


Image 11: Exposed wood on the *San Felipe*



Image 12: Exposed wood on the *San Felipe*



Image 13: Biological life on the *San Felipe*