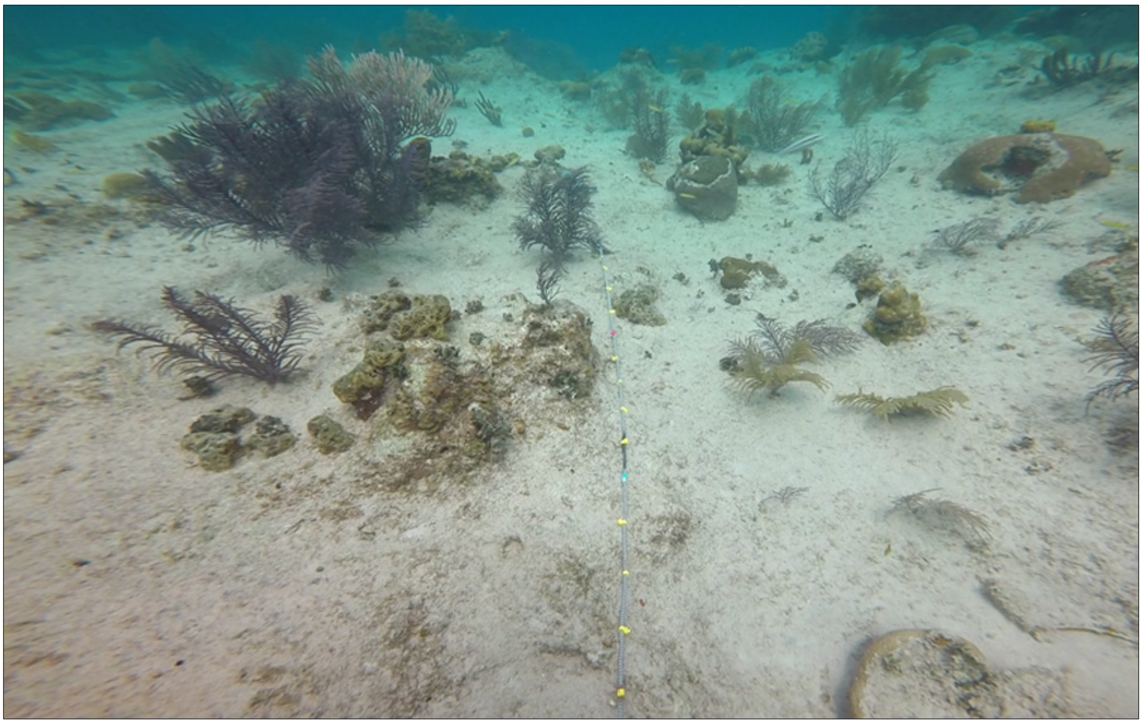
Benthic Habitat Characterization Survey

George Town Harbor Berthing Program

August 2015



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1 Introduction

CSA Ocean Sciences Inc. (CSA) was contracted by West Indian Marine Group (WIM) and their respective client, the Cayman Islands Government, to conduct a Benthic Habitat Characterization Survey, which consists of ecological and geophysical surveys in support of a proposed dredging and land reclamation program for cruise berthing facilities in George Town Harbor—the George Town Harbor berthing program. The berthing program is considered to have both direct and indirect impacts on the marine habitats within George Town Harbor. The direct impact area of the George Town Harbor berthing program is projected to be approximately 32.5 acres (ac) (131,523 m^2) shown in **Figure 1** (W.F. Baird & Associates Coastal Engineers Ltd. [Baird], 2015).

CSA's Benthic Habitat Characterization Survey, which focused on the direct impact area within the proposed footprint of George Town Harbor berthing program, was conducted to meet the following objectives:

- Delineate seafloor habitats;
- Characterize seafloor habitats;
- Quantify hard and soft corals within the projected direct impact area; and
- Assess potential options to mitigate impacts.

In meeting these stated objectives, the survey primarily focused on characterizing the coral-supporting habitats within the study area. This report provides the methods and results for the Benthic Habitat Characterization Survey conducted from 27 to 30 June 2015 as well as descriptions of various field-tested options that could be considered for mitigation of impacts from the program.

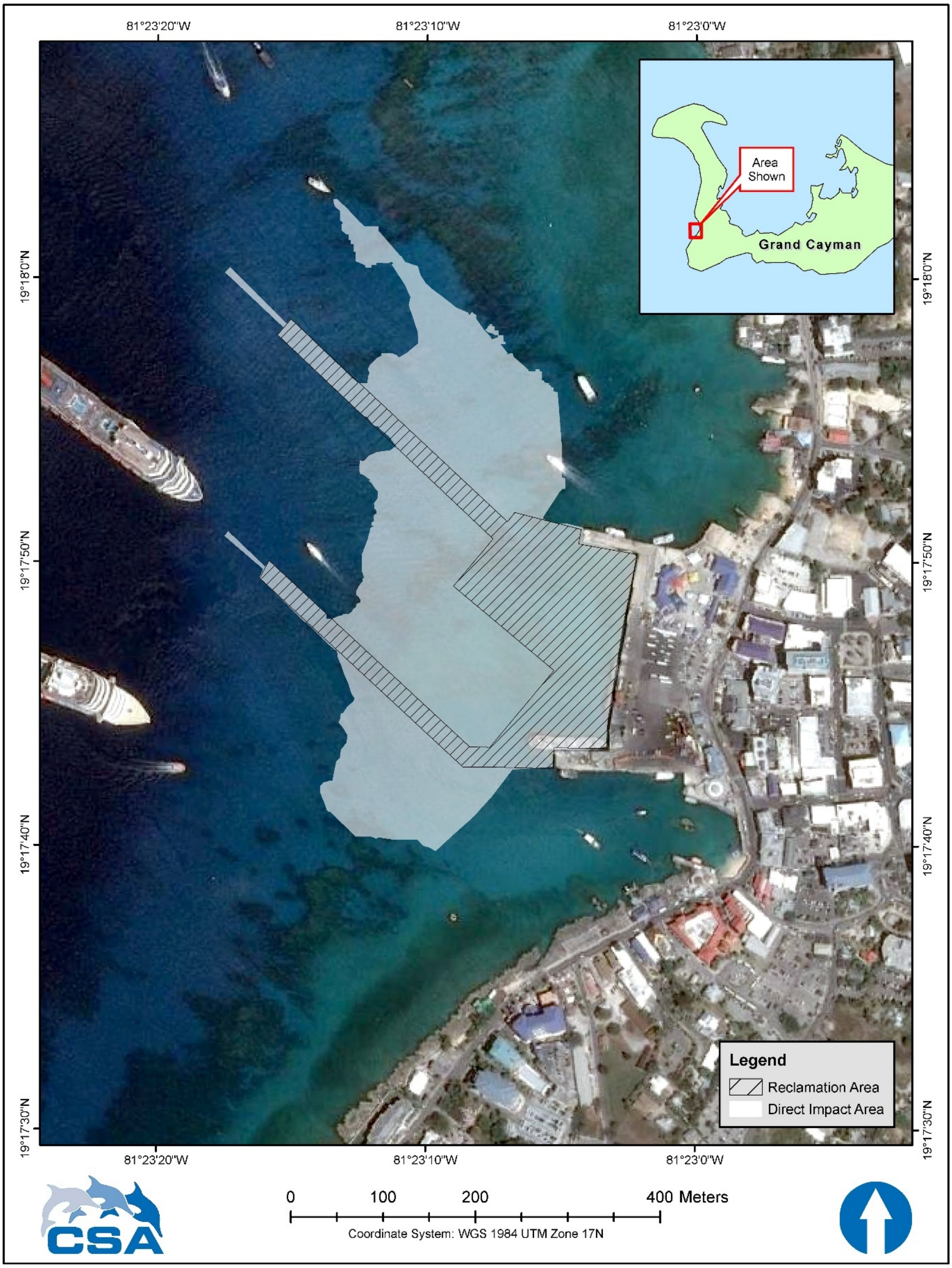

Figure 1. The projected direct impact area from dredging and land reclamation activities associated with the George Town Harbor berthing program (From: W.F. Baird & Associates Coastal Engineers Ltd., 2015).

2 Methods

The Benthic Habitat Characterization Survey included ecological and geophysical survey activities that were concurrently conducted within George Town Harbor specific to the berthing program's projected direct impact area. In the ecological survey, scientific divers collected visual, photographic, and *in situ* data for delineating and characterizing seafloor habitats. The geophysical survey was conducted to collect side-scan sonar data to delineate and characterize seafloor substrates based on interpretation of acoustic signatures associated with relative sediment consolidation and topographic relief.

2.1 NAVIGATION AND SURVEY VESSELS

The ecological survey used a Garmin global positioning system (GPS) receiver for positioning and WIM's Booby Cay, a 30-ft utility vessel, with suitable deck space for conducting safe diving operations.

The geophysical survey used a GPS receiver interfaced with Hypack navigation and data acquisition software for positioning and WIM's Barker Cay, another 30-ft utility vessel, for remote sensing tow system operations.

2.2 ECOLOGICAL SURVEY

2.2.1 Ground Truthing

AAUS-certified scientific divers[1] conducted bounce dives at various locations within the berthing program's direct impact area to ground truth habitat mapping in the Draft Environmental Statement for the Proposed Cruise Berthing Facility, Grand Cayman (Draft ES) (Baird, 2015). Bounce dives were conducted throughout the area projected to be directly impacted by berthing program operations. Visual observations and video photography were collected to document the habitat type at each ground-truth location.

2.2.2 Habitat Characterization Transects

Benthic habitat characterization transects were conducted by scientific divers within the projected direct impact area that were interpreted as spur and groove and mixed patch reef habitats (Baird, 2015). At each sampling location, four parallel 10 m × 1 m transects were established to document habitat type, estimate percent coverage of substrates and biota, identify coral taxa, and quantify corals (hard and soft). The four parallel 10-m transects were positioned approximately 3 m apart and defined using survey lead lines. Data collected *in situ* along each transect included point-intercept counts, quantification quadrats, and qualitative/quantitative video. Point-intercept identifies and counts substrate and biota that are traversed by the transect lead line. The 10-m lead line is demarcated at 10 cm intervals. The substrate type (sand, rubble, and rock) or biological taxa (lowest practical taxonomic level) was identified at each 10-cm demarcation; 100 points were assessed along each transect.

Quantification quadrats were used to determine hard coral taxa, size classifications, and density; soft coral type (sea plume, sea rod, sea whip, and sea fan), size classifications, and density were also

[1] All CSA divers are certified in SCUBA by internationally recognized organizations, trained as specialty divers for using enriched air (Nitrox), and are American Academy of Underwater Sciences (AAUS) certified Scientific Divers. Additionally, all divers are formally trained in cardiopulmonary resuscitation (CPR) and first aid and all CSA dive operations are conducted in a manner consistent with Association of Diving Contractors (ADC) standards, Occupational Safety and Health Administration [OSHA], U.S. Army Corps of Engineers [USACE], and U.S. Coast Guard regulations. CSA is covered by Marine Employer's Liability Insurance, which includes Diving Workman's Compensation, General Marine Liability (including Completed Operations), Jones Act, and U.S. Longshoreman & Harbors. CSA is a member of the ADC.

determined within each quadrat. These data were collected within 0.5 m × 0.5 m quadrats along the full length of the 10-m transects abutting both the right and left side of the lead line. A total of 40 quantification quadrats were established for each 10-m transect; 20 quadrats along the right and left sides of the lead line. Corals present within the quadrat were counted, identified, and roughly measured to determine size classification (<10 cm, 10 to 25 cm, 25 to 40 cm, and >40 cm). To avoid count redundancy, corals traversed by the lead line (portion of the colony to the right and left) were counted only within quadrats along the right side of the lead line. Corals that extended outside and forward of the quadrat (into the boundary of the subsequent quadrat) were counted only once.

Video data were collected by scientific divers along each transect with the lead line in the video's field of view. To collect quantitative data, a video camera and housing were maintained at a constant height of approximately 50 cm above the substrate, held perpendicular to the substrate, and slowly moved along the length of the transect. A Go-Pro high-definition digital video camera was mounted on the quantitative video camera housing and oriented at an oblique angle relative to the substrate to simultaneously collect qualitative data.

2.3 GEOPHYSICAL SURVEY

A Klein 3900 system was used to collect side-scan sonar data within the proposed footprint of George Town Harbor berthing program. The 3900 system is an extremely high-resolution digital sonar that provides excellent range and resolution. The system includes a towfish transceiver processing unit (TPU), custom-configured laptop, and 50 m of lightweight tow cable. The TPU was towed along pre-plotted survey lines to provide complete coverage within the survey area.

Side-scan sonar uses sound to obtain distance and reflective characteristics of bottom features, providing images that look like photographs. Side-scan sonar data provide the general location and morphology of bottom features, including hard- (**Image 1**) and soft bottom substrates (**Image 2**). Imaging the seafloor with side-scan sonar is accomplished by towing over the study area a side-scan instrument (towfish) equipped with a linear array of transducers that emit, and later receive, an acoustic pulse at a specific frequency range. The acoustic pulse is designed to be wide in the across-track direction and narrow in the along-track direction, as depicted by the bright yellow fan-shaped area in **Figure 2**.

The reflected acoustic energy received by the side-scan sonar tow vehicle provides information on the general distribution and characteristics of the surficial sediment and outcropping strata. In general, if all other parameters are constant, consolidated substrates and rougher surfaces (e.g. hard bottom) will backscatter more energy than unconsolidated substrates and smoother surfaces and, therefore, return higher amplitude signals. The resultant side-scan sonar images can be put together as a mosaic (i.e., georeferenced composite) that represents the acoustic characteristic of the seafloor, which can be interpreted to determine various substrate types and features.

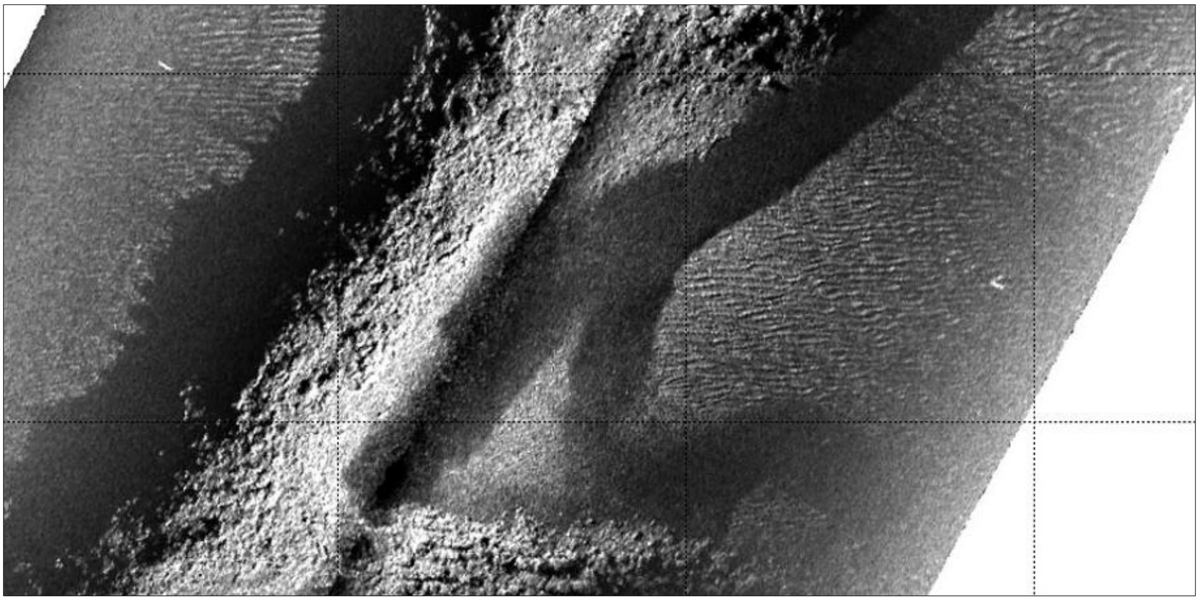

Image 1. Side-scan sonar of hard bottom substrates shows variable topographic vertical relief indicated by degree of shadowing within the image.

Image 2. Side-scan sonar of soft bottom substrates, which distinguishes sediment textures and subtle topographic features such as small sand waves and sediment tiering.

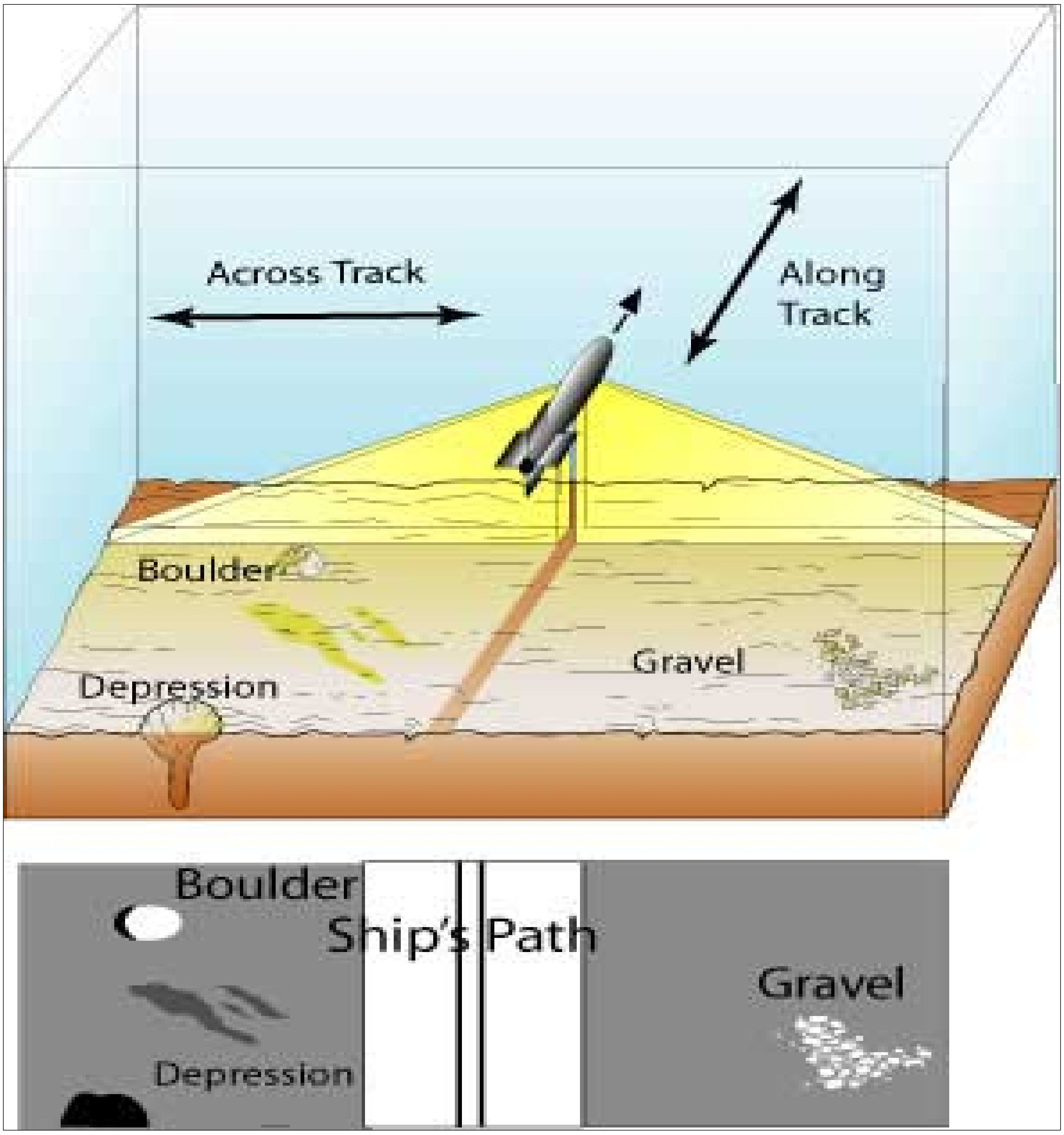

Figure 2. The towfish is shown at the apex of the across-track of the acoustic beam (yellow fan-shaped area). Acoustic-reflected image (light gray area) shows detected seafloor features. The brown stripe below the towfish shows the along-track dimension.

3.1 GROUND TRUTHING

Ground truthing was conducted at 61 locations within the direct impact area of the berthing program based on habitat mapping in the Draft ES (Baird, 2015). The navigational coordinates, habitat classification, and water depth for each ground-truth location is presented in **Table 1**. The ground-truth locations relative to the projected direct impact area associated with the George Town Harbor berthing program (Baird, 2015) are shown in **Figure 3**. Limits on survey time precluded sampling in the southernmost portion of the direct impact footprint where minimal reef habitat was expected based on Baird (2015) habitat mapping.

Table 1. Navigational coordinates, habitat classification, and water depth for each ground-truth location.

Station Designation	Navigational Coordinates		Habitat Classification	Water Depth (m)
	Longitude	Latitude		
BD49	-81.3863	19.2965	Man-made artifact	7.3
BD33	-81.3842	19.2970	Hard bottom with sand veneer	3.7
BD40	-81.3848	19.2971	Hard bottom with sand veneer	5.5
BD42	-81.3843	19.2966	Hard bottom with sand veneer	4.3
BD43	-81.3844	19.2965	Hard bottom with sand veneer	4.9
BD45	-81.3848	19.2967	Hard bottom with sand veneer	5.8
BD47	-81.3852	19.2967	Hard bottom with sand veneer	6.4
BD53	-81.3850	19.2964	Hard bottom with sand veneer	5.5
BD54	-81.3847	19.2964	Hard bottom with sand veneer	5.2
BD56	-81.3847	19.2962	Hard bottom with sand veneer	5.5
BD57	-81.3845	19.2961	Hard bottom with sand veneer	16
BD58	-81.3851	19.2960	Hard bottom with sand veneer	6.1
BD65	-81.3850	19.2959	Hard bottom with sand veneer	6.1
HB2	-81.3858	19.2961	Hard bottom with sand veneer	5.2
HB3	-81.3851	19.2961	Hard bottom with sand veneer	6.1
HB4	-81.3851	19.2966	Hard bottom with sand veneer	6.1
S1	-81.3856	19.2963	Hard bottom with sand veneer	6.1
HB1	-81.3862	19.2963	Hard bottom with sand veneer	5.5
PR2	-81.3854	19.2968	Hard bottom with sand veneer	7.0
S2	-81.3856	19.2969	Hard bottom with sand veneer	7.3
S4	-81.3846	19.2968	Hard bottom with sand veneer	5.2
S ALT	-81.3855	19.2965	Hard bottom with sand veneer	5.2
BD60	-81.3868	19.2961	Exposed reef formation	11.3
PR5	-81.3851	19.2969	Exposed reef formation	6.7
BD24	-81.3867	19.2970	Exposed reef formation	10.4
BD32	-81.3846	19.2976	Exposed reef formation	5.2
BD38	-81.3855	19.2971	Exposed reef formation	6.7
R3-New	-81.3863	19.2986	Exposed reef formation	11.3
R ALT	-81.3866	19.2967	Exposed reef formation	9.8
BD23	-81.3863	19.2974	Exposed reef formation	9.1
BD37	-81.3859	19.2970	Exposed reef formation	6.7

Table 1. (Continued).

Station Designation	Navigational Coordinates		Habitat Classification	Water Depth (m)
	Longitude	Latitude		
BD6	-81.3866	19.2990	Exposed reef formation	10.4
PR1	-81.3857	19.2966	Exposed reef formation	6.7
PR3	-81.3849	19.2973	Exposed reef formation	7.3
R1	-81.3850	19.2982	Exposed reef formation	7.9
R2	-81.3860	19.2971	Exposed reef formation	4.3
R3	-81.3863	19.2985	Unconsolidated substrate	~11.0
BD1	-81.3863	19.2999	Unconsolidated substrate	10.7
BD10	-81.3854	19.2987	Unconsolidated substrate	9.8
BD11	-81.3852	19.2989	Unconsolidated substrate	9.1
BD12	-81.3864	19.2984	Unconsolidated substrate	11.3
BD15	-81.3858	19.2983	Unconsolidated substrate	~9.0
BD16	-81.3859	19.2980	Unconsolidated substrate	9.1
BD17	-81.3864	19.2976	Unconsolidated substrate	11.0
BD19	-81.3857	19.2978	Unconsolidated substrate	8.8
BD2	-81.3875	19.2995	Unconsolidated substrate	44
BD20	-81.3853	19.2979	Unconsolidated substrate	8.2
BD21	-81.3850	19.2981	Unconsolidated substrate	9.1
BD28	-81.3856	19.2974	Unconsolidated substrate	7.9
BD3	-81.3862	19.2996	Unconsolidated substrate	11.3
BD30	-81.3851	19.2977	Unconsolidated substrate	6.7
BD34	-81.3849	19.2974	Unconsolidated substrate	7.3
BD48	-81.3861	19.2967	Unconsolidated substrate	8.5
BD5	-81.3859	19.2992	Unconsolidated substrate	10.7
BD50	-81.3857	19.2966	Unconsolidated substrate	7.6
BD67	-81.3848	19.2954	Unconsolidated substrate	7.6
BD8	-81.3867	19.2986	Unconsolidated substrate	18.2
R4	-81.3860	19.2994	Unconsolidated substrate	11.0
BD41	-81.3842	19.2967	Unconsolidated substrate	4.6
BD46	-81.3852	19.2968	Unconsolidated substrate	7.3
BD66	-81.3849	19.2956	Unconsolidated substrate	7.9

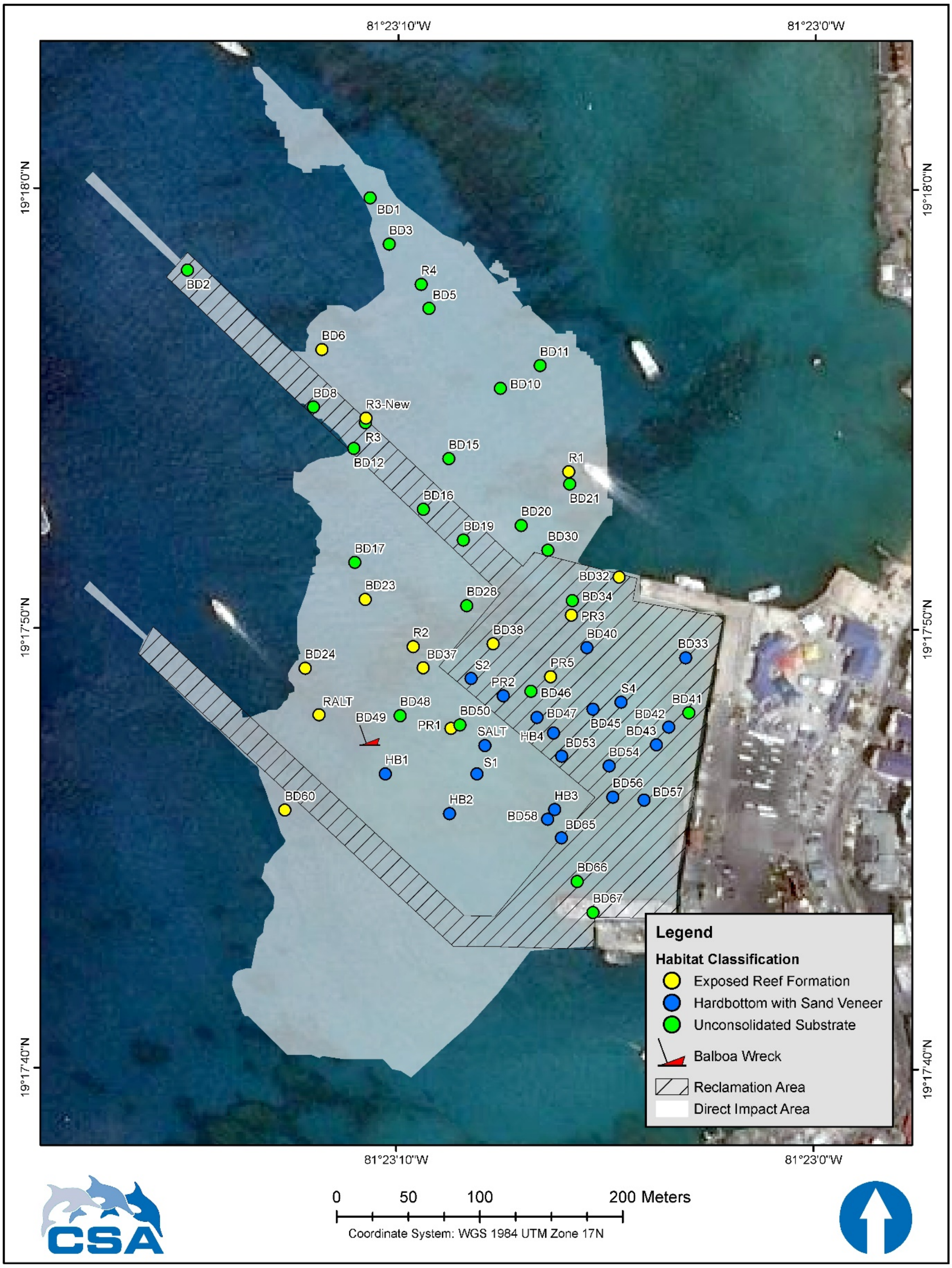

Figure 3. Ground-truth locations within the berthing program's direct impact area (i.e., dredging and land reclamation area) as described in W.F. Baird & Associates Coastal Engineers Ltd. (2015).

The 61 ground-truth locations included 43 bounce dive and 17 transect sampling dive locations. A marker buoy was deployed at each dive location according to the pre-plotted navigational coordinates. Each dive location was classified by general substrate type present in the immediate vicinity of the marker buoy anchor and predominant coral-supporting habitat along sampling transects. The four substrate classifications were: 1) hard bottom with sand veneer, 2) exposed reef formation, 3) unconsolidated substrate, and 4) man-made artifact. Both hard bottom with sand veneer and exposed reef formation habitats supported a biological community with corals; corals were not associated with the areas classified as unconsolidated substrate. A single bounce dive location was positioned directly on the *Balboa* wreck and was subsequently classified as a man-made artifact (**Image 3**). Portions of the submerged wreck supported a biological community that included corals (**Images 3** and **4**).

Image 3. One of the 61 bounce dive locations was positioned directly on the *Balboa* wreck and was subsequently classified as a man-made artifact.

Image 4. Portions of the submerged *Balboa* wreck supported a biological community that included corals.

The distribution of the coral supporting habitats as generally delineated in **Figure 3** (i.e., yellow and blue dots) is corroborated by the 1999 aerial image (**Image 5**) of George Town Harbor showing seafloor habitats offshore of the existing dock area. The hard bottom with sand veneer habitat is predominantly along the shoreward portion of the berthing program's projected direct impact area (**Figure 3**). The exposed reef formation habitat is a relatively continuous parallel to shore feature generally distributed along the seaward edges of the hard bottom with sand veneer habitat (**Image 5**).

Image 5. A 1999 aerial image of George Town Harbor showing seafloor habitats offshore of the existing dock area (image was provided by Lands & Survey Department of Cayman Islands Government).

Hard bottom with sand veneer habitat classification was applied to low-relief carbonate substrate which was overlaid by unconsolidated substrate in highly variable amounts (**Image 6**). The variable thickness of the sand veneer and relatively level topography appear to have limited the amount of epibiotic development on this habitat classification (**Image 7**). This habitat had relative distributional continuity along the shoreward central portion of the berthing program's projected direct impact area (**Figure 3**).

Image 6. Hard bottom with sand veneer habitat classification was applied to low-relief carbonate substrate, which was overlaid by a covering of unconsolidated substrate.

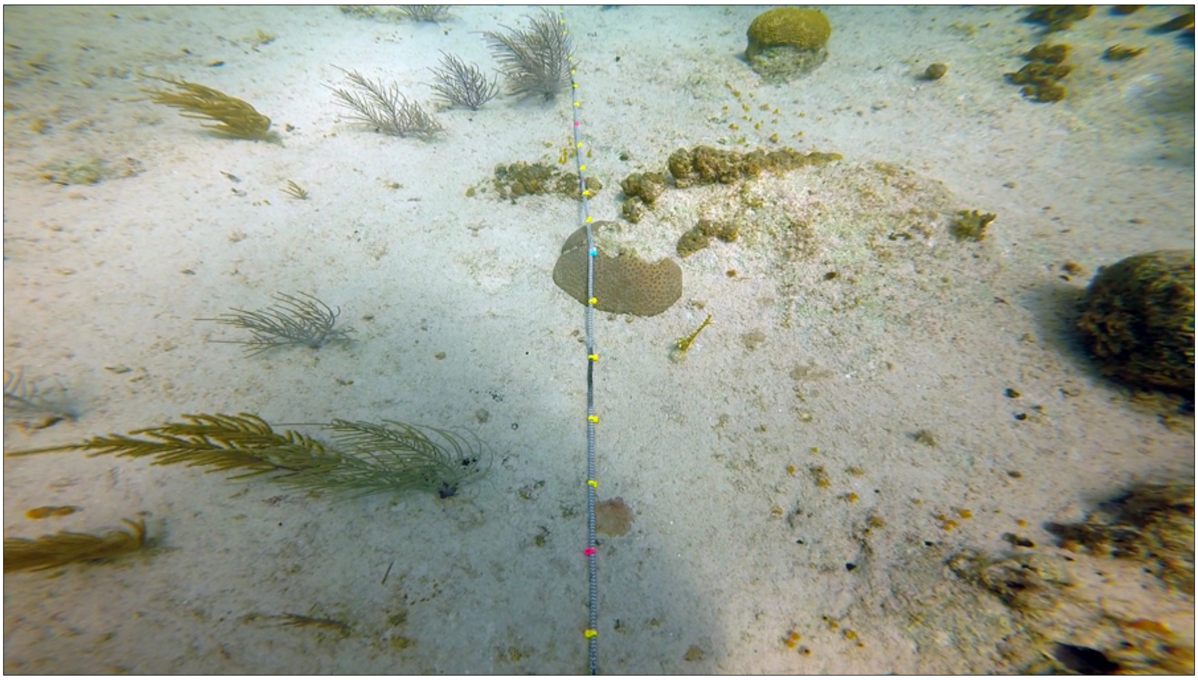

Image 7. The hard bottom with sand veneer habitat with low-relief topography appeared to have limited epibiotic development.

Exposed reef formation classification was applied to irregular relief carbonate substrates that supported a relatively productive epibenthic community with a relative high diversity and abundance of corals. The exposed reef formation habitat is characterized by elevated topographic features, which are primarily a product of hermatypic coral deposition and subsequent disproportional erosion of these deposits (**Image 8**). The irregular topography of the areas classified as exposed reef formation provides elevated substrate and considerable microhabitat (**Image 9**), which visually distinguishes it from the hard bottom with sand veneer habitat.

Image 8. The exposed reef habitat is characterized by elevated topographic features, which are primarily a product of hermatypic coral deposition.

Image 9. Irregular topography observed in the exposed reef formation habitat, which provides elevated substrate and considerable microhabitat.

3.2 HABITAT CHARACTERIZATION TRANSECTS

A total of 15 transect sampling stations were used to characterize the biological communities in each habitat that supported hard and soft corals (**Table 1)**. Nine transect sampling stations were located in the hard bottom with sand veneer habitat; six were located in the exposed reef formation habitat. The random orientation of one exposed reef formation habitat station included sampling along the *Balboa* wreck. Although the wreck was classified as a man-made artifact, it provided habitat for coral development and was subsequently considered with the exposed reef formation habitat sampling. Data collected at each coral-supporting habitat were used to characterize these habitats specific to coral taxonomic composition, density, and size-class distribution. Additionally, point-intercept data were collected to estimate areal coverage of substrate types and epibiota within the various habitats.

The number of hard coral species (with fire coral, *Millepora* spp.) and soft coral groupings observed during transect sampling at the coral-supporting habitats are presented in **Table 2**. The exposed reef formation habitat supported a more diverse hard coral assemblage than the hard bottom with sand veneer habitat with 22 and 14 taxa, respectively. The most abundant coral taxa for each habitat was the starlet coral (*Siderastrea radians*), which has a high recruitment rate and is an early colonizing species (Lirman and Manzello, 2009). Other more commonly observed coral taxa included the lettuce coral (*Agaricia* spp.), mustard hill coral (*Porites astreoides*), and boulder star coral (*Orbicella annularis*).

Table 2. Number of hard coral species (with fire coral, *Millepora* spp.) and soft coral groupings observed during transect sampling at the coral-supporting habitats.

Taxa/Habitats	Hard Bottom with Sand Veneer	Exposed Reef Formation	Total
Hard Corals			
Agaricia spp.	74	481	555
Colpophyllia natans	--	3	3
Dichocoenia stokesi	5	2	7
Diploria labyrinthiformis	3	7	10
Eusmilia fastigiata	--	5	5
Favia fragum	99	51	150
Madracis decactis	5	30	35
Madracis auretenra	--	5	5
Manicina areolata	--	3	3
Millepora spp.	29	61	90
Montastrea cavernosa	11	44	55
Orbicella annularis	131	273	404
Orbicella faveolata	2	65	67
Orbicella franksii	--	5	5
Porites astreoides	94	317	411
Porites divaricata	--	2	2
Porites furcata	--	22	22
Porites porites	--	22	22
Pseudodiploria strigosa	78	10	88
Siderastrea radians	788	625	1,413
Siderastrea siderea	67	214	281
Stephanocoenia intersepta	31	22	53
Soft Corals			
Sea plumes	158	32	190
Sea rods	12	149	161
Sea whips	7	67	74
Sea fans	9	25	34
Encrusting soft coral	58	73	131

The hard and soft coral densities from coral-supporting habitats within the survey area are presented in **Table 3**. The overall coral densities (colonies m^{-2}) were much greater in the exposed reef formation habitat than the hard bottom with sand veneer habitat. The hard coral density for the hard bottom with sand veneer and exposed reef formation habitats ranged from less than 1 to 8 colonies m^{-2} and from 7.6 to 15.2 colonies m^{-2}, respectively. Similarly the soft coral density for the hard bottom with sand veneer and exposed reef formation habitats ranged from 0 to 4.1 colonies m^{-2} and from 0.1 to 5.3 colonies m^{-2}, respectively. The densities for the coral-supporting habitats as presented in **Table 3** were used in estimating the number of corals that could be potentially impacted within the proposed footprint of George Town Harbor berthing program.

Table 3. Hard and soft coral densities from coral-supporting habitats within the survey area.

Habitat Classification/ Station Designation	Coral Density (colony m^{-2})	
	Hard Corals	Soft Corals
Hard Bottom with Sand Veneer		
PR2	5.9	0.5
PR5	7.3	0.7
HB1	8.0	4.1
HB2	6.8	0.5
HB3	5.8	0.2
HB4	0.8	0.1
S1	1.9	0.2
S4	1.0	0.0
S-ALT	0.3	0.1
Overall	**4.7**	**0.8**
Exposed Reef Formations		
R1	10.3	1.2
R2	9.5	0.1
R3 New	12.1	5.3
R-ALT	15.2	3.2
PR1	11.6	1.4
PR3	7.6	0.4
Overall	**11.1**	**1.7**

The size of the coral colonies is an important consideration in coral translocation. Typically, corals selected for translocation would be at least 10 cm in diameter. **Table 4** presents the percentage of hard coral specimens in each size classification from coral-supporting habitats within the survey area. The majority of hard corals within the study area were less than 10 cm in diameter and therefore probably less than 5 years old. More than 85% of the hard corals from the hard bottom with sand veneer habitat were less than 10 cm. The dominance of small corals coupled with the relatively low density of coral would make coral translocation a very laborious process in the hard bottom with sand veneer habitat. Although also dominated by smaller corals, the exposed reef formation habitat, with 34.2% of hard corals greater than 10 cm, would facilitate more efficient and productive coral translocation efforts. The relative abundance of the various coral size classifications as presented in **Table 4** were used in estimating the number of corals that could be considered for translocation to mitigate for potential impacts from the George Town Harbor berthing program.

Table 4. Percentage of hard coral specimens for each size classification from coral-supporting habitats within the survey area.

Habitat Classification/ Station Designation	Percent of Hard Corals per Size Class			
	<10 cm	10 to 25 cm	25 to 40 cm	>40 cm
Hard Bottom with Sand Veneer				
PR2	71.0	22.4	5.5	1.1
PR5	65.6	27.6	5.0	1.8
HB1	77.5	16.6	3.8	2.2
HB2	86.7	11.1	1.9	0.4
HB3	97.0	2.1	0.0	0.9
HB4	95.2	4.8	0.0	0.0
S1	89.3	6.7	4.0	0.0
S4	93.5	3.2	3.2	0.0
S-ALT	100.0	0.0	0.0	0.0
Overall	**86.2**	**10.5**	**2.6**	**0.7**
		14.8		
Exposed Reef Formation				
R1	50.6	36.3	8.9	4.2
R2	55.6	33.9	8.5	2.1
R3 New	71.3	20.3	6.4	2.0
R-ALT	79.5	17.5	2.3	0.7
PR1	68.9	27.1	3.1	0.9
PR3	68.9	23.6	4.7	2.8
Overall	**65.8**	**26.5**	**5.7**	**2.1**
		34.2		

Similarly, the size of soft coral colonies is an important consideration in translocation. However, since soft corals have much faster growth rates than hard corals specimens, less than approximately 25 cm may not be considered for translocation. **Table 5** presents the percentage of soft coral specimens in each size classification from coral-supporting habitats within the survey area. Although the majority of soft corals within the study area are less than 25 cm in height and probably around 2 to 3 years old, both coral-supporting habitats still have considerable populations of larger soft corals (>25 cm in height). The exposed reef formation habitat has more than 30% of soft corals with greater than 25-cm height, which could be considered for translocation. The relative abundance of the various soft coral size classifications were used to estimate the number of soft corals that could be considered for translocation to mitigate for potential impacts from the George Town Harbor berthing program.

Table 5. Percentage of soft coral specimens for each size classification from coral-supporting habitats within the survey area.

Habitat Classification/ Station Designation	Percent of Soft Corals per Size Class			
	<10 cm	10 to 25 cm	25 to 40 cm	>40 cm
Hard Bottom with Sand Veneer				
PR-2	50.0	50.0	0.0	0.0
PR-5	16.0	56.0	24.0	4.0
HB-1	18.9	56.7	8.5	15.9
HB-2	77.8	22.2	0.0	0.0
HB-3	57.1	28.6	0.0	14.3
HB-4	0.0	33.3	0.0	66.7
S-1	66.7	22.2	11.1	0.0
S-4	0.0	0.0	0.0	0.0
S-Alt	100.0	0.0	0.0	0.0
Overall	**48.3**	**33.6**	**5.5**	**12.6**
	81.9		**18.1**	
Exposed Reef Formation				
R-1	40.0	37.5	20.0	2.5
R-2	50.0	50.0	0.0	0.0
R-3 New	15.5	14.5	21.8	48.2
R-Alt	19.0	25.4	4.0	51.6
PR-1	17.9	62.5	8.9	10.7
PR-3	8.3	75.0	0.0	16.7
Overall	**25.1**	**44.2**	**9.1**	**21.6**
	69.3		**30.7**	

The percent coverage of various biotal groups and substrate types from coral-supporting habitats are presented in **Table 6**. It should be noted that the line-intercept method may underestimate the coverage of fauna with an aerial component (i.e., canopy). Similar to the coral density data, the percent coverage of hard and soft corals is greater for the exposed reef formation habitat than the hard bottom with sand veneer habitat. The epifaunal coverage provided by corals and sponges was three times greater on the exposed reef formation than the hard bottom with sand veneer habitat.

Table 6. Percent cover of biota and substrates on coral-supporting habitats within the survey area.

Biota/Substrate	Habitat Classification	
	Exposed Reef Formation	Hard Bottom with Sand Veneer
Biota:		
Algae	51.20	16.80
Hard coral	5.82	1.84
Soft coral	0.99	0.36
Sponge	2.31	0.63
Substrate:		
Unconsolidated substrate	15.10	15.57
Sediment over hard bottom	14.32	62.98
Hard bottom	10.27	1.82

3.3 GEOPHYSICAL SURVEY

Side-scan sonar data were used to help document and map the distribution of consolidated and unconsolidated substrates within the footprint of the George Town Harbor berthing program (**Figure 4**).

Figure 4. Mosaic of side-scan sonar data used to help document and map the distribution of consolidated and unconsolidated substrates within George Town Harbor.

The acoustic (side-scan sonar) and visual data were used in conjunction to delineate the aerial coverage of consolidated substrates within the berthing program's projected direct impact area. Coverage of coral-supporting hard bottom habitats (consolidated substrates) within George Town Harbor includes hard bottom with sand veneer and exposed reef formation classifications (symbolized with purple cross-hatch) as shown in **Figure 5**.

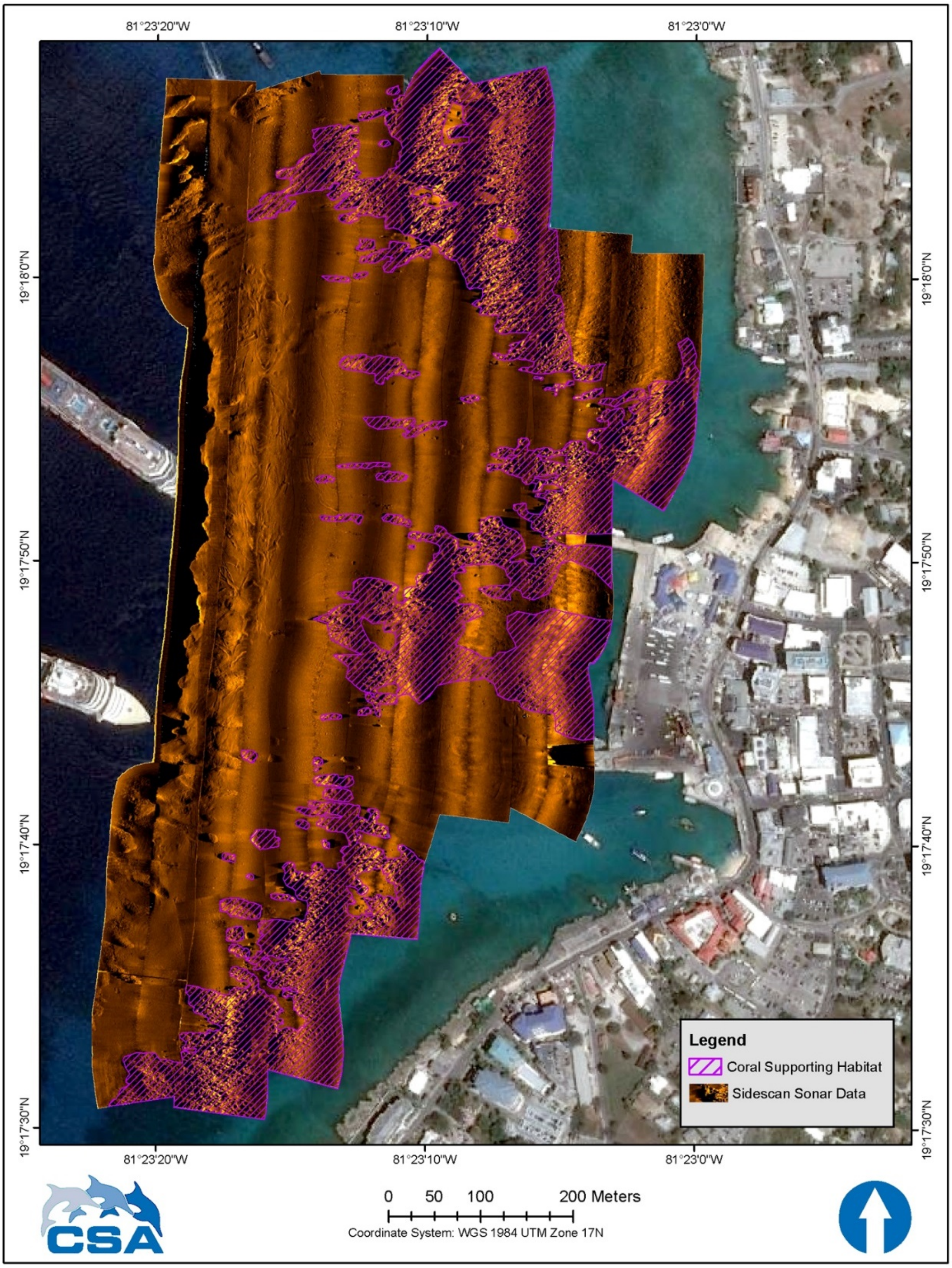

Figure 5. Coverage of coral-supporting habitat (consolidated substrates) within George Town Harbor includes hard bottom with sand veneer and exposed reef formation habitat classifications.

3.3.1 At-Risk Coral Resources

To estimate the amount of coral-supporting habitat directly impacted by the berthing program, the delineated aerial coverage of consolidated substrates based on interpretation of side-scan sonar and visual data (i.e., ground-truth locations) was integrated with the George Town Harbor berthing program direct impact area (Baird, 2015) using ArcMap software (**Figure 6)**. The total direct impact area of the berthing program is 32.5 ac (131,523 m^2). The total area for coral-supporting habitats (symbolized with purple cross-hatch in **Figure 6**) inside the boundary of the direct impact area is 11.2 ac (45,350 m^2). The 11.2 ac of coral-supporting habitat is estimated to comprise approximately 4.3 ac (17,560 m^2) of hard bottom with sand veneer habitat and 6.9 ac (27,790 m^2) of exposed reef formation habitat. The remaining portion of the direct impact area is considered to be unconsolidated sediment (i.e., sand, shell hash, and gravel).

Hard bottom with sand veneer habitat (shown with blue dots in **Figure 6**) was generally characterized by relatively level topography and limited epibiotic development (**Image 10**). Coral densities for the hard bottom with sand veneer habitat ranged from less than 1 to 8 colonies m^{-2} of hard corals and from 0 to 4.1 colonies m^{-2} of soft corals. The hard bottom with sand veneer habitat was dominated by smaller corals with more than 85% of the hard corals measuring less than 10 cm and more than 80% of the soft corals measuring less than 25 cm. The dominance of small corals coupled with low coral density would make coral translocation very laborious in this habitat type.

Exposed reef formation habitat (shown in yellow dots in **Figure 6**) had irregular and relatively high topographic relief that supported a productive epibenthic community with 22 observed hard coral taxa (**Image 11**). Coral densities for the exposed reef formation habitat ranged from 7.6 to 15.2 colonies m^{-2} of hard corals and from 0.1 to 5.3 colonies m^{-2} of soft corals. Although the exposed reef formation habitat was dominated by smaller corals, with 34.2% of hard corals greater than 10 cm and considerable populations of larger soft corals (>25 cm in height) suitable for translocation, the coral community characteristics of this habitat would facilitate efficient and productive coral translocation efforts.

The coral resources at risk from the direct impact from dredging and land reclamation activities for the cruise berthing facility within George Town Harbor includes an estimated 391,001 hard corals and 61,291 soft corals. These estimates are based on calculations of average densities of hard and soft corals from each coral-supporting habitat. Of the 391,001 hard corals at risk, more than 274,000 are less than 10 cm in diameter and relatively young specimens. Similarly, of the 61,291 at-risk soft corals, more than 44,200 are less than 25 cm in height and relatively young specimens. Subsequently, the estimated number of hard corals (>10 cm in diameter) and soft corals (>25 cm in height) that could be considered for translocation is over 116,800 and over 17,000, respectively.

Some apparent differences can be seen between habitat delineation based on ground truthing and the interpretation of side-scan sonar data used to map the distribution of consolidated and unconsolidated substrates (**Figure 6)**. These differences emerge because the surveys are conducted at different levels of spatial resolution on a rather heterogeneous landscape. For example, small sand patches present in a landscape dominated by coral-supporting hard bottom may be observed during dive operations but may not be discernable from side-scan sonar imagery. Thus, the randomly selected ground-truthed habitat classification points may have occurred in an area mapped as coral-supporting habitat based on the more generalized sonar classification.

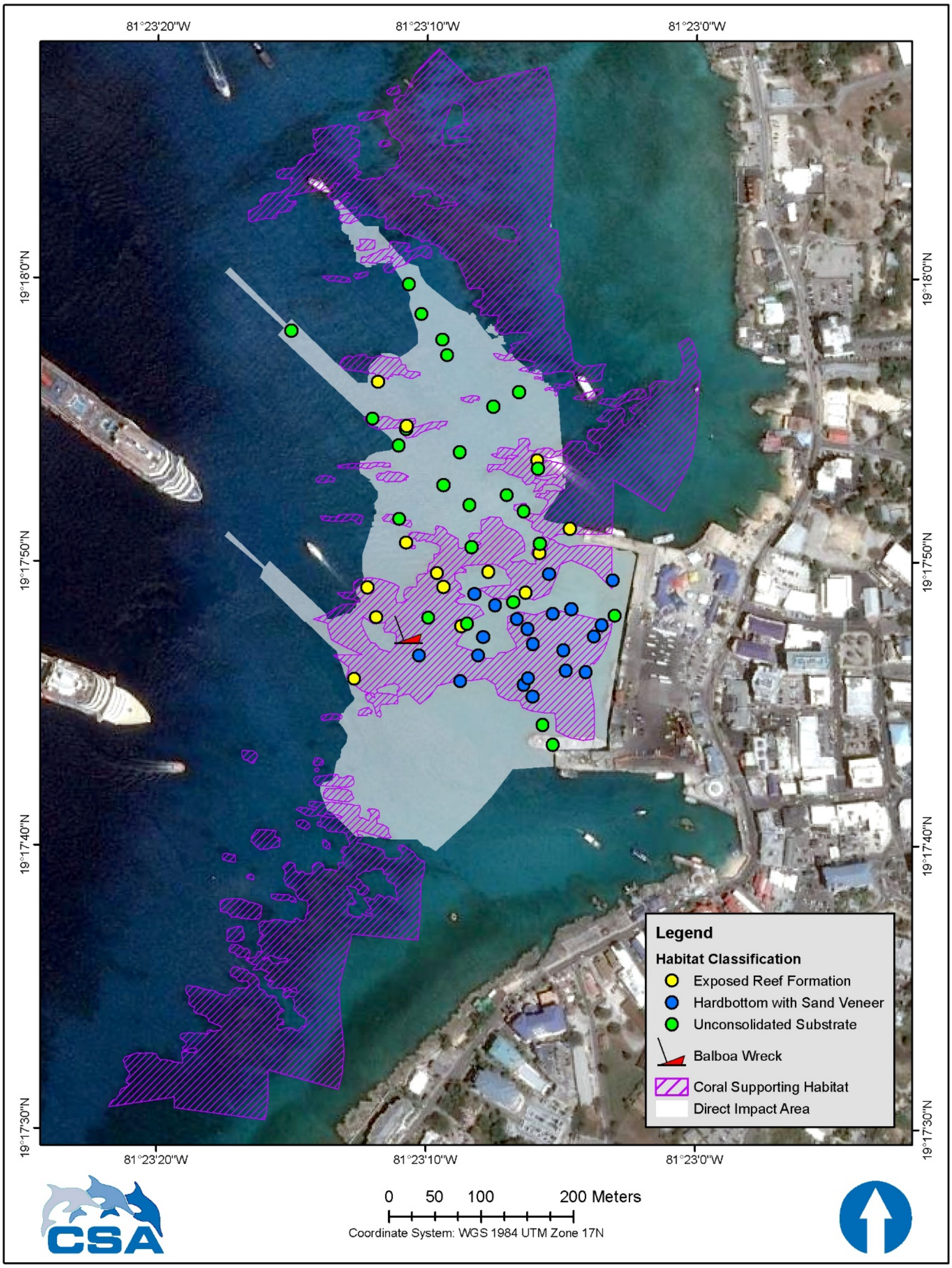

Figure 6. Distribution of coral-supporting habitats within the berthing program's projected direct impact area relative to the interpretation of side-scan sonar data and ground-truth locations.

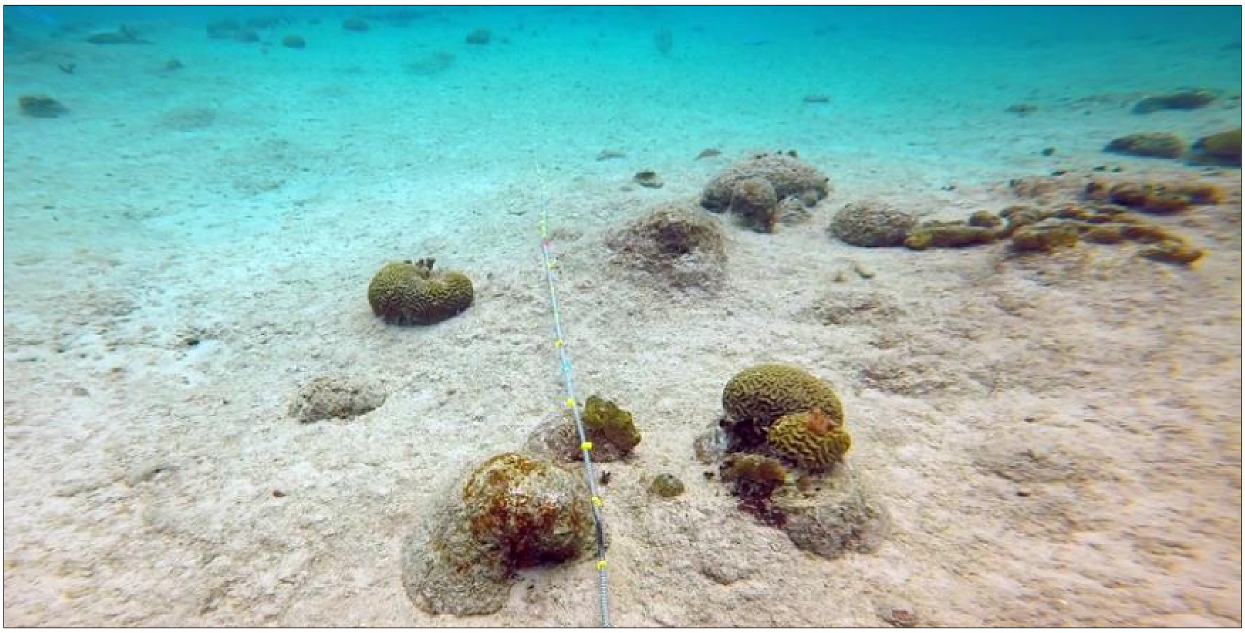

Image 10. Representative image of the hard bottom with sand veneer habitat.

Image 11. Representative image of the exposed reef formation habitat.

4 Mitigation Options

Possible options to address impacts to coral resources include both in-kind and out-of-kind mitigation. In-kind mitigation is the creation, restoration, or enhancement of a habitat type similar to the habitat that is adversely impacted by an activity. Likewise, out-of-kind mitigation is the creation, restoration, or enhancement of a habitat type different than the habitat that is adversely impacted by an activity. The mitigation options, as prepared, are not comprehensive but reflect our experience and best professional judgment regarding field-tested methods for mitigation of natural resource damages. CSA considers these mitigation options as possibly suitable for application to the George Town Harbor berthing project.

Coral translocation would probably be the primary mitigation option for the reducing impacts associated with the berthing project. Coral translocation, if done properly, can significantly reduce the loss of coral tissue and the ecological services provided by corals. CSA began doing coral reattachment during the infancy of this technique and procedural development. Senior marine specialists at CSA have been instrumental in refining reattachment procedures and have field-tested applications for reattachment of coral, soft coral, and large structural sponges as a means of accelerating habitat recovery.

CSA has conducted coral reattachment on more than 60 programs associated with marine construction, ship groundings, anchor damage, and habitat enhancement worldwide. The scale of these programs is quite variable, ranging from relatively few corals to many thousands. A recent Caribbean program involved reattaching more than 20,000 corals using hundreds of tons of cement (**Images 12a** and **12b**). Some of these programs were monitored by an outside party to determine the relative success of the coral reattachment technique using cement. Outside parties that have monitored CSA coral reattachment programs include the U.S. National Oceanographic and Atmospheric Administration (NOAA), National Coral Reef Institute (NCRI), and Florida Marine Research Institute. CSA coral reattachment has been proven to be very successful, and monitoring reports assessing the relative success of these programs are summarized here.

- A ship grounding program completed by CSA monitored by an independent third party reported 100% survivorship and coral colony stability 2 years following restoration in the Florida Keys National Marine Sanctuary (FKNMS). The program included coral reattachment, reef structural repair, and placement of artificial reef structure (Franklin et. al., 2005).
- CSA reattached more than 400 corals in restoration modules in the southern portion of the FKNMS. Monitoring of the site 3 years after the restoration found all modules were stable with elevated coral coverage due to growth of reattached corals (Schittone et. al., 2006).
- More than 1,000 coral colonies were removed from an offshore construction site in Broward County, Florida, temporarily cached for the construction period, and reattached to a submerged structure following construction activities. Monitoring of the coral stability and health was conducted at the reattachment site over a 3-year period and showed a 97% success rate (National Coral Reef Institute, 2004).

Outside monitoring that verifies successful reattachment and coral survivorship is the only science-based means to establish credibility in providing these types of services. All of CSA's reattachment programs use experienced AAUS-certified scientific divers with similar field-tested techniques using cement as the primary bonding agent. The monitoring results, as presented for relatively small programs, expresses the expected relative success for CSA coral reattachment/translocation regardless of the scale of the program.

(a)

(b)

Image 12. Successful reattachment of staghorn coral (*Acropora cervicornis*), which is listed as Critically Endangered in the International Union for Conservation of Nature Red List of Threatened Species. Location of vessel grounding shown denuded of coral assemblage (a) and site shown approximately 6 years after reattachment of coral and other biota (b).

4.1 CORAL TRANSLOCATION

Coral translocation may significantly accelerate both the expansion of coral habitat and recovery of existing, impacted areas. The objective and primary benefit of coral translocation is to reduce or minimize potential impacts to these resources as a result of a particular activity (**Images 13a** and **13b**). The procedures for coral translocation as a feasible mitigation option to be considered for Cayman resources are addressed in this section.

Site Reconnaissance Surveys should be conducted at both the coral donor site (i.e., berthing project direct impact footprint) and recipient (i.e., translocation) site(s). Based on the results of the CSA Benthic Habitat Characterization Survey there may be adequate baseline information specific to the George Town Harbor berthing project coral assemblage. However, if any aspect of the current data is considered inadequate after further review an assessment would be conducted to augment the existing data concerning 1) delineation of specific coral colony collection areas within the donor site, 2) estimation of coral abundances, and 3) characterization of coral community species composition and size-classes, in particular coral listed under the endangered species act. A very important consideration for successful coral translocation is proper recipient site selection. The parameters used to confirm the suitability of the recipient site for coral reattachment include 1) similarity to the donor site concerning oceanographic conditions (e.g. water quality) and water depth, 2) adequate space for transplants, 3) distance from donor site, and 4) proximity to future development.

Collection and Transport would be conducted following the reconnaissance surveys and identification and/or establishment of suitable recipient site(s). Coral colonies would be collected "in-whole" representing all taxa present within the donor site. *In lieu* of collecting all corals present, the colonies selected for translocation would be prioritized based on relative health and size to provide representative specimens of all species present at the donor site. The relative abundance (i.e., proportional distribution) of the various coral species selected for translocation would be similar to their occurrence at the donor site (**Image 14**).

Prior to transport, selected coral colonies would be removed from the point of attachment. If conditions precluded immediate translocation of the dislodged corals, they can be stabilized and properly cached pending transport to the donor site. Corals properly cached can remain viable for transportation for over 2 months, barring any extreme oceanographic events.

The coral transport method will depend primarily on the how long it takes to get from the donor site to the recipient site(s) and the number of corals being relocated from the donor site. The coral transport options are the "containerized-cover" method and the "pool-system" method. The "containerized-cover" method involves placing and securing the coral colonies in a suitable container and covering the corals with seawater-dampened sheets. The "pool system" method involves the containerization of coral colonies and placement in a continuous fresh seawater flow-through pool. This "pool system" method was designed and previously used by CSA and was used for a long-distance transport (duration over 2 hours and a distance of over 45 km) for large numbers of coral colonies.

Reattachment of the corals would be conducted immediately after transport and deployment of the specimens at the recipient site(s). Reattachment locations should be selected ensuring a spatial distribution of the reattached corals that is similar to natural conditions of the selected recipient site(s) coral habitat. Following selection and preparation of attachment sites, a concrete mixture would be prepared and applied to the reattachment surfaces. Reattached corals would be checked intermittently during reattachment operations to ensure their stability and the aesthetic quality of the reattachment matrix.

(a)

(b)

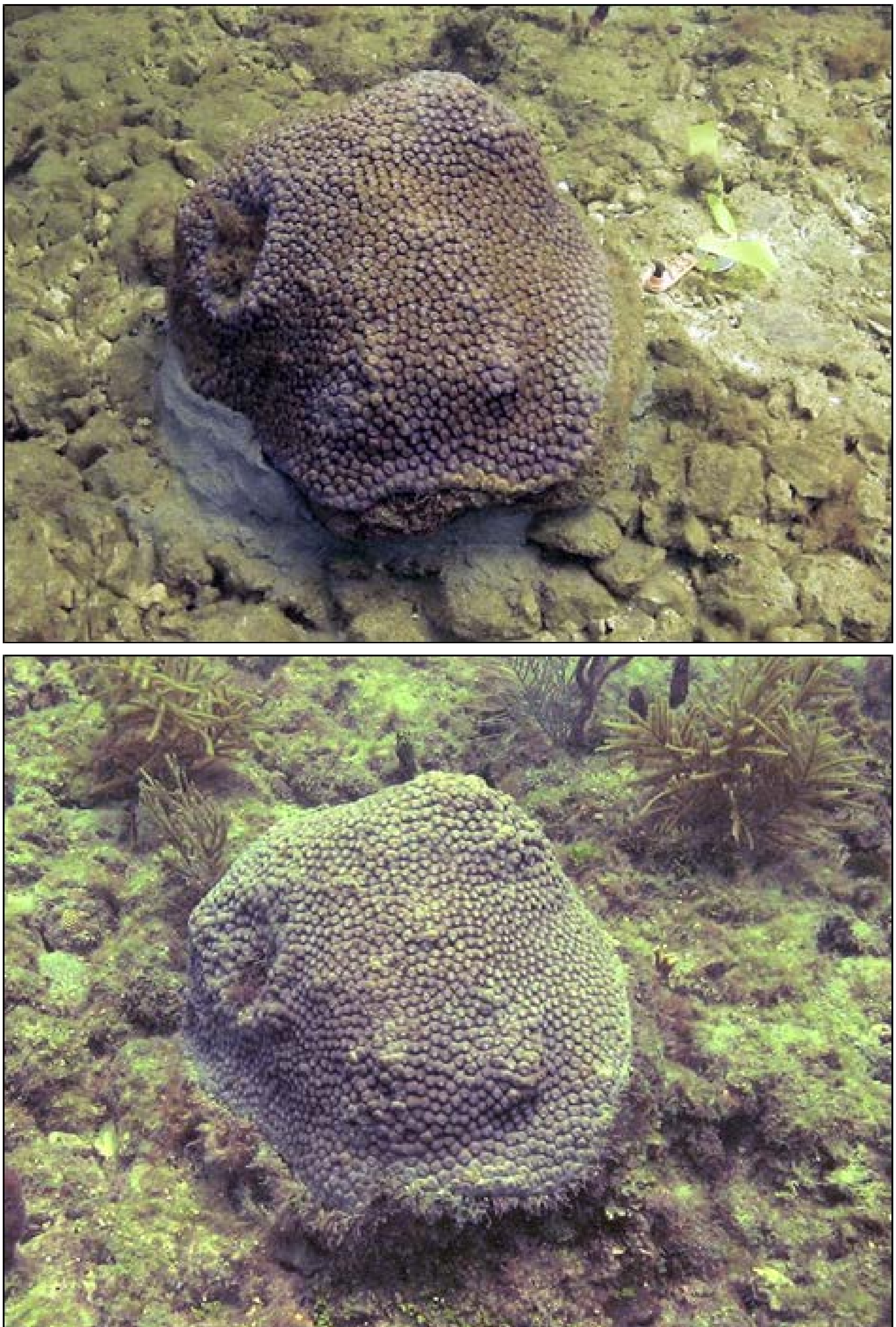

Image 13. Colony of great star coral (*Montastraea cavernosa*) at vessel grounding site shown immediately (a) and approximately 4 years after reattachment (b).

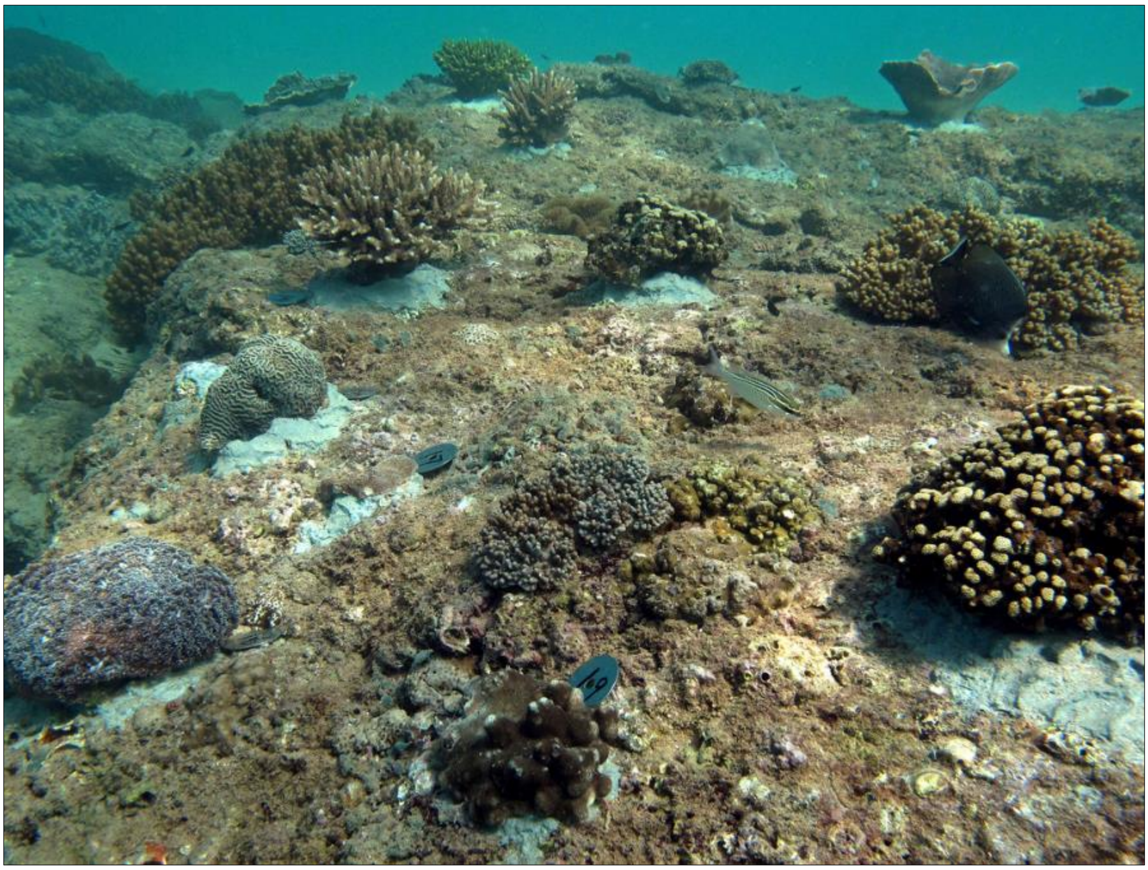

Image 14. Reattached coral colonies that were translocated from a pipeline construction site to an appropriate recipient site.

Based on CSA's experience with coral translocation programs, not all at-risk corals are moved from the direct impact location. The percentage of at-risk corals to be translocated usually takes into consideration the larger and older specimens, any endangered species, and less common components of the assemblage. Typically, the final number of at-risk corals selected for translocation is cooperatively decided between regulators and proponents based on a consensus of acceptable level of impact from the proposed activities.

4.2 CORAL NURSERY

The objective of a coral nursery is to provide biological stock to facilitate replenishing natural populations of corals. The nursery stock provides a source of coral specimens to repopulate areas where natural reefs have been impacted as a result of anthropogenic events. In addition to mitigating sites where human impacts have reduced coral densities, nurseries can be used to replenish sites where natural coral populations have declined due to significant environmental events (i.e. coral bleaching due to oceanographic temperature extremes). The use of coral nursery stock is intended to greatly accelerate biological recovery of recipient sites.

A coral nursery could be stocked from various sources including fragments from natural populations, transplants from existing man-made or derelict structures, and/or "at-risk" corals within natural reef environments such as the George Town Harbor berthing project area. The nursery option for impact mitigation can be applied to all coral morphological types including the slower-growing mound corals. Nurseries can be developed to specifically address reintroduction and increased abundance of the slower-growing mound corals that may have reduced recruitment rates.

4.3 SUBSTRATE AUGMENTATION

The objective of substrate augmentation is to establish hard substrate features to provide refuge for mobile fauna and suitable habitat for natural recruitment or translocation of epibenthos. Substrate augmentation can be used to restore structural complexity of an impacted habitat and/or to mitigate for loss of exposed hard substrate associated with a project activity, such as the berthing project (**Image 15**). Augmentation increases substrate surface area and availability for epibenthic settlement; surface area and abundance of sessile macroinvertebrates are variables which influence the diversity and abundance of fishes (Ferriera et. al., 2001). Other factors that influence the number of reef fish species and their abundance is substrate and habitat complexity in the form of vertical relief and number of interstices (Luckhurst and Luckhurst, 1978; Dennis and Bright, 1988), which can be considerably enhanced by proper substrate augmentation programs.

Image 15. Stabilized substrate at a vessel grounding site was used to restore structural complexity of an impacted habitat and/or to mitigate for loss of exposed hard substrate.

Primary forms of substrate augmentation are artificial reef modules and natural materials, which may be of limited availability on Grand Cayman. Artificial reef modules come in all shapes, sizes and composition. Modules can be pre-fabricated on land for subsequent deployment offshore or fabricated on-bottom depending on the application and requirements of the substrate augmentation program (**Image 16**). On-bottom fabrication of modules removes the potential need for heavy equipment and commercial dive operations. Applications of substrate augmentation include general fisheries enhancement, construction (e.g. dredge) impact mitigation, coral reef restoration, and biological nurseries.

Image 16. Successful reattachment of elkhorn coral (*Acropora palmata*), which is listed as Critically Endangered on the International Union for Conservation of Nature Red List of Threatened Species. Coral fragments were reattached within a pre-fabricated reef module using cement. This restoration program was monitored by U.S. National Oceanographic and Atmospheric Administration (Schittone et. al., 2006).

4.4 DEBRIS REMOVAL

The objective of debris removal from the reef habitats is to reduce the threat of damage to natural resources from persistence and dispersal of abandoned debris on reefs. The most prevalent debris are the metal-mesh fish traps, buoy lines, and monofilament fishing lines. The overall process for debris removal will include diver visual observations, document debris location, and physical removal. All work should be conducted with the utmost care in preventing collateral injury to the reef resources during the debris removal process (**Image 17**).

Image 17. Debris removal should be conducted in a manner to prevent collateral injury to reef resources.

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