South Florida/Caribbean Network

National Park Service
Inventory and Monitoring Division

Standing Operating Procedure RF01

Statistical Sampling Design—Version 2.0

Please cite this as:

South Florida/Caribbean Network. 2025. Statistical Sampling Design—Version 2.0. South Florida/Caribbean Network Standard Operating Procedure NPS/SFCN/SOP—RF01. South Florida/Caribbean Network, Palmetto Bay, Florida.

Purpose

This standard operating procedure (SOP) describes the sample grid, sampling design, and habitat classification and stratification schemes used in South Florida and the U.S. Virgin Islands. It also describes the approach for optimal sample allocation and selection of sites for reef fish visual census (RVC) surveys.

Revision History Log

Revision Date	Author	Changes Made	Reason for Change	New Version #
2012	Mike Feeley	Grid cells 50 × 50 meters (164 × 164 feet) USVI	Switched from a polygon based simple random design survey focused in and around the parks to an island-wide shelf stratified random survey.	1.1
2014	Mike Feeley	Grid cells 100 × 100 meters (328 × 328 feet) SFL	Improved habitat maps.	1.2
2017	Mike Feeley	Stationary point counts started in USVI (discontinued transect surveys)	Uniform methodology adopted for Caribbean / Florida region (including Puerto Rico and Flower Gardens).	1.3
2020	Mike Feeley	Grid cells 50 × 50 meters and quantified rugosity variable SFL	Improved habitat maps.	2.0
2020	Mike Feeley	Reduced fish surveys to 1 pair of divers (1 SSU) per primary sampling unit SFL	Co-location and effort needed for NCRMP benthic data collection	2.0

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Introduction

This SOP outlines a one-stage stratified random sampling design developed over the past 20-plus years and successfully applied to estimate important metrics for reef fish populations in the Florida Keys, Tortugas, and the United States Virgin Islands (e.g., Ault et al. 1999; Ault et al. 2002; Ault et al. 2013; Ault et al. 2021; but see also Table 1). This statistical sampling design is also the basis for estimating reef fish population abundances in other regions of the world including Puerto Rico, The Flower Gardens, Southeast Florida (Palm Beach to Martin County) and the U.S. territorial waters of the Pacific Ocean (Ault et al. 2008; Smith et al. in 2011a; Nadon et al. 2015; Heenan et al. 2017; Ault et al. 2018). Results from these fishery independent surveys have been used directly in management actions for the National Park Service, the State of Florida and the Southeast Data Assessment and Review (SEDAR) stock assessment projects within the NOAA Fisheries Southeast region.

The one-stage stratified random design increases the efficiency of sampling by effectively stratifying the survey domain based on variables that influence the variability of fish population densities. This includes stratifying the sample domain based on habitat (USVI only), cross-shelf zone (Florida only), sub-region, management zone, depth and rugosity (Florida only). Bryan et al. (2013) determined that a stratified random sample, rather than a simple random design, resulted in improved population estimates in the U.S. Virgin Islands. Our survey design follows a Neyman (or optimal) allocation in which sample units are allocated according to both stratum size and the stratum standard deviations of specific fish species densities. This scheme increases the efficiency of sampling by allocating greater sampling effort to those strata that are larger and more variable while smaller, less variable strata receive less effort. The scheme is designed to collect reef fish data on a scale that supports population level estimates for the entire domain, but also allows for rigorous comparisons inside and outside of fisheries management zones.

Probability sampling is a long-standing, theoretically, and methodologically advanced field of statistics developed for the specific purpose of estimating metrics (e.g., means, proportions, and totals) for a population within a finite spatial domain (Hansen et al. 1953; Cochran 1977; Särndal et al. 1992; Lohr 1999). A critical component of a survey design is the creation of a sampling frame which includes a complete, explicit list of all possible sampling units. It is necessary to know the probability (P) of selecting a single sample, as well as to have the ability to account for all the area in each survey stratum. A geo-spatially referenced grid, where grid size is a balance of map resolution and species range, has been shown to work for other tropical marine surveys (Ault et al. 1999; Smith et al. 2011b; Bryan et al. 2016). Each grid cell is considered an independent sample unit from which a sample can be selected. The sampling domain and grid cells (Primary-Sampling Unit; PSU) are based on published benthic habitat maps that are delineated by habitat classification schemes (and not diver assessments) and weighted by strata. The secondary-sampling unit (SSU; the cylinder visual assessments) are selected by divers on hardbottom within the PSU. Through a detailed data validation process the stratum of the sample may be corrected to the field-observed description.

Sample Frame

Stratification and Survey Domain

Florida Keys and Tortugas

South Florida is divided into two regions, the Florida Keys and the Tortugas. The Florida Keys region includes all mapped area of hardbottom habitat less than 33 meters (108.3 feet [ft]) depth between Miami (South of Government Cut) and Key West (western end of Boca Grande Key). Similarly, the Tortugas region contains all mapped hardbottom habitats shallower than 33 meters on two distinct limestone bank formations; the atoll-like Dry Tortugas, the location of Dry Tortugas National Park, and Tortugas Bank, located west of the park, which also includes the Tortugas North Ecological Reserve.

To control for spatial variation in population metrics, the survey domains are divided into strata based upon: (1) cross-shelf zone (Florida Keys only), depth and rugosity; (2) geographic sub-region and (3) management zone (Figures 1 and 2; Tables 2 and 3; Appendix A). There are 11 stratum categories in the Florida Keys and nine in the Tortugas subregions. The geographic sub-regional stratification variable (Biscayne; upper, middle, and lower Keys; Dry Tortugas and Tortugas Bank) and cross-shelf zone in the Florida Keys (e.g., Inshore, Mid Channel as described by FWC [2020b] and included as Appendix A) are used to account for oceanographic and geological features that influence the distribution, community dynamics, and biotic composition of reefs in Florida (Marszalek et al. 1977; Shinn et al. 1977). Additionally, sub-regional stratification is meant to ensure broad spatial coverage of sampling effort. Management zones (i.e., no-take marine reserves) are incorporated as another stratification variable that delineate areas open or closed to consumptive activities. Water depth is classified into four variables (shallow: 0–11.9 meters [0–39 ft; D1], mid: 12–21.9 meters [39.3–71.9 ft; D2], deep: 22–33 meters [72.2–108.3 ft; D3] on the Forereef; 0–11.9 meters [D0] on the Inshore, Mid Channel and Offshore Patch Reef). Rugosity data (RVC diver-collected is primary, remote-sensed is secondary) are used to designate the quantitative average relief values for grid cells and are used to assign the cells to a rugosity stratum (R1–R4, and RU; see *Grid cells* section below). Average substrate vertical relief (rugosity) is expressed as less than 0.15 meters (0.5 ft; R1), 0.15 – 0.259 meters 0.5–0.85 ft; R2), 0.26 – 0.39 meters (0.85–1.27 ft; R3), greater than or equal to 0.40 meters (1.31 ft; R4) and unknown (RU). The RU rugosity category tends to be in deeper waters where remote sensing data are lacking. The new rugosity categories are quantitative and replace previous qualitative descriptions that categorized habitats as low, medium and high relief. A composite scheme with habitat ranked by complexity: (1) Contiguous Spur and Groove, (2) Contiguous, (3) Isolated Patch Reef, (4) Aggregate Patch Reef, (5) Pavement, and (6) Rubble is still used to define the habitat type of individual grid cells and helps define the cross-shelf zones (Table 1). We feel a composite scheme does the best job of assigning habitat type that would influence reef fish occurrence and abundance. There are 11 habitat (zone)-depth-rugosity strata in the Florida Keys and nine in the Tortugas (Table 2). Combining all stratum with managed reserve areas yields 14 strata across the Florida Keys and 18 strata in the Tortugas. The Florida Keys is stratified into one "protected" marine reserve zone and one "open" fished zone. The Tortugas is stratified into two marine reserves (Dry Tortugas NP and Tortugas North Ecological Reserve) and one "open" fished

area (Table 3). Because the NPS also has special management interest in the park units, the stratification data for Biscayne NP and Dry Tortugas NP RNA are also presented in Tables 2 and 3. This stratification scheme provides flexibility to merge strata and address various questions in an evolving survey design.

Table 1. Habitat classification decision rules used to classify habitat in primary sampling units (grid cells) (from Bryan et al. 2013).

Scheme	Description
Hierarchical	Grid cell classification was prioritized by descending habitat type: USVI à (1) Linear Reef, (2) Patch Reef, (3) bedrock, (4) pavement, and (5) scattered coral/rock; Florida à (1) Contiguous Spur and Groove, (2) Contiguous, (3) Isolated Patch Reef, (4) Aggregate Patch Reef, (5) Pavement, and (6) Rubble. If a cell contains multiple habitat types, the grid cell is assigned the highest priority habitat that made up a minimum of 10% of the area of the cell.
Majority Area	Each grid cell was assigned the majority habitat class within the cell.
Composite	Grid cells grouped into more complex classes and less complex. If a combined 20% of the habitat in a cell was in the more complex classes, the majority area was used to assign the habitat class from one of those classes. If cells had less than 20% of high complexity habitat, the majority area was used.

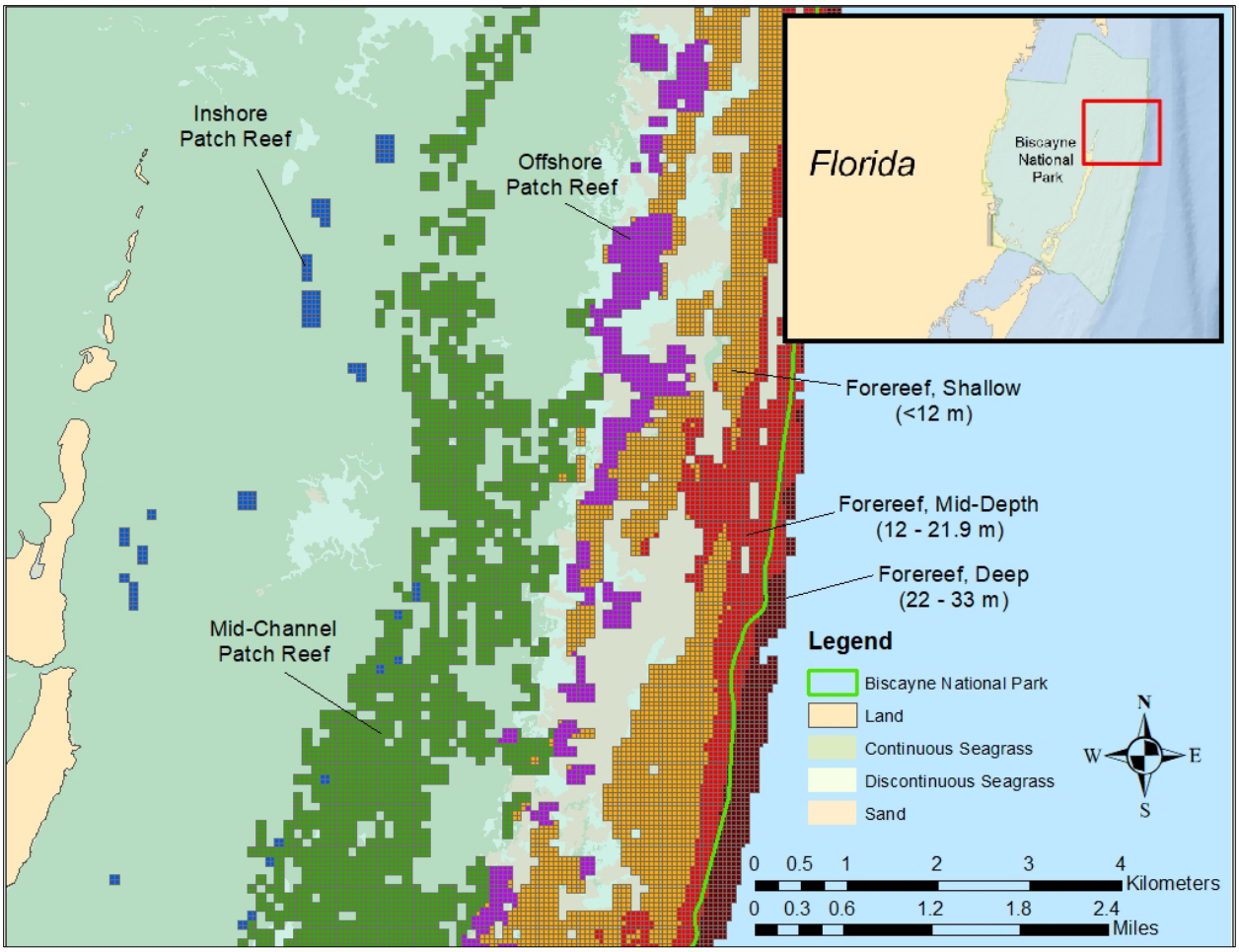


Figure 1. Cross-shelf distribution of habitat zones for the Florida Keys within Biscayne National Park defined by the 50 × 50 meter (164 × 164 ft) primary sampling unit gridfile. The number of possible primary sample units (N_h) calculated for each stratum for the Florida Keys sub region is provided in Table 2.

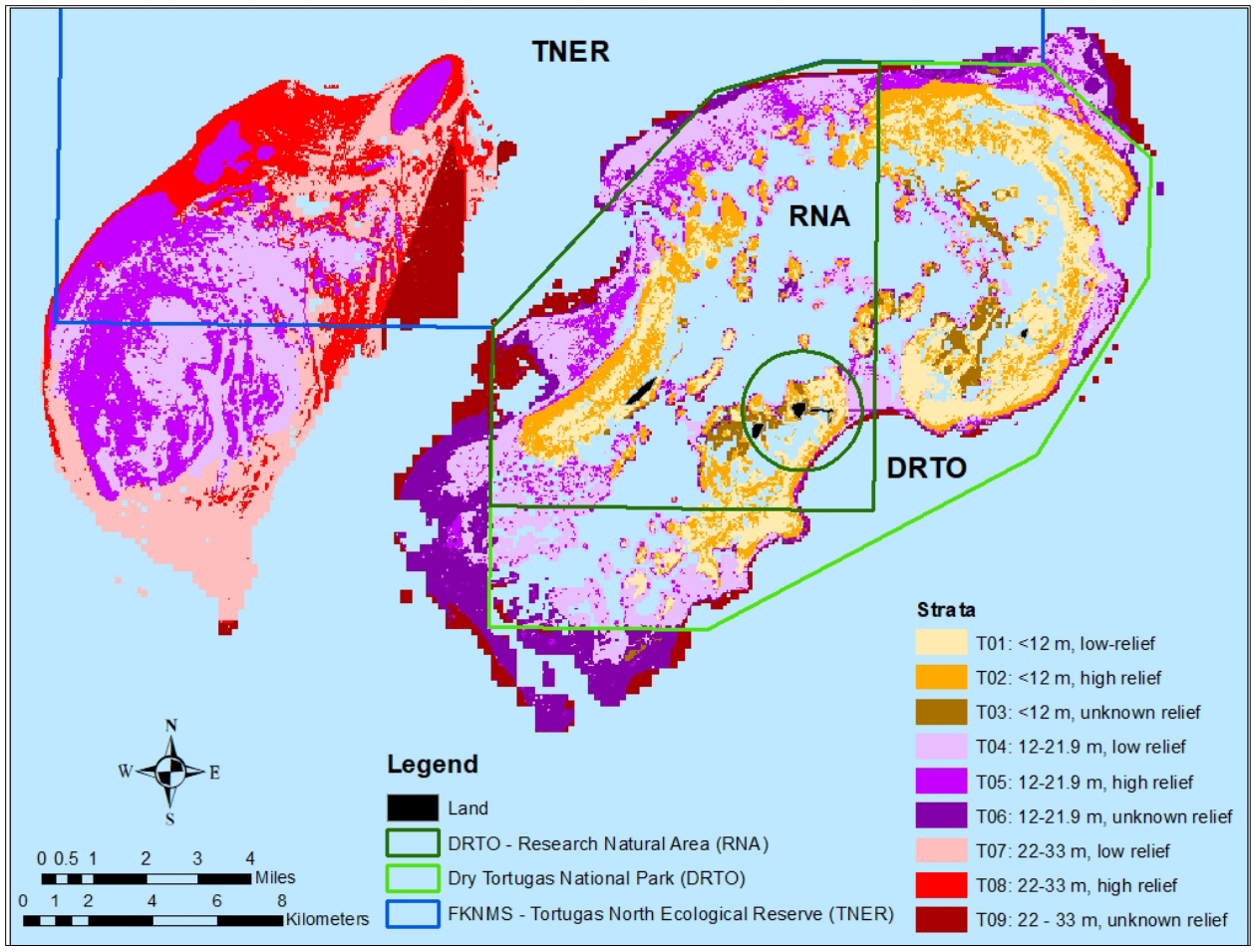


Figure 2. Strata for the Tortugas subregion defined by the 50 × 50 meter (164 × 164 ft) primary sampling unit gridfile. The number of possible primary sample units (Nh) calculated for each stratum within the Tortugas sub region is provided in Table 3.

United States Virgin Islands

In the U.S Virgin Islands, two broad geographic regions are recognized, which are further stratified by habitat and depth and include comprehensive management zones of the National Park Service. The two regions include the shallow island shelf hardbottom areas (< 30 meters [98.4 ft] depth) of: (1) St. Thomas / St. John and (2) St. Croix (Figure 3). Within the St. Thomas / St. John region, all hardbottom habitats within Virgin Islands National Park (VIIS), Virgin Islands Coral Reef National Monument (VICR) and all hardbottom habitats outside of these management zones, including the midshelf reef are targeted for sampling. In the St. Croix region, targeted sampling zones include hardbottom habitats within Buck Island Reef National Monument (BUIS), Salt River Historic Park and Ecological Reserve (SARI) and hardbottom habitat outside these management zones. Trends in standard deviation for optimization species by region were investigated by Bryan et al. (2013) and an overall habitat and depth classification scheme was chosen that was a compromise among species and regions. The stratification scheme includes five hard bottom classifications, two depth categories, shallow (0–11.9 meters [0–39 ft]) and deep (12–30 meters [39.4–98.4 ft]) depth and marine reserves. The USVI regions are broken into 12 habitat-depth strata in both St. Thomas/St. John and in St.

Croix. This includes a "hard" habitat category that we are presently in the process of updating to one of the five habitat classes. There are three managed marine reserves in St. Thomas/St. John and two in St. Croix. These areas create 44 total strata in St. Thomas/St. John and 40 strata in the St. Croix region (Tables 4 and 5). Note that not all strata are included in all areas (no category).

The benthic habitat maps for the U.S. Virgin Islands were originally delineated from aerial surveys into 21 distinct habitat types (Kendall et al. 2001). Hardbottom benthic habitats were divided into five types: Linear Reef, Patch Reef, Bedrock, Pavement, Scattered Coral/Rock. A detailed description of these habitat types can be found in Kendall et al. (2001) and in Appendix B. Multibeam data collected annually from 2004 until 2016 were used to determine bathymetry information (Battista 2015a–f; Battista 2016; Battista et al. 2017). National Park Service boundaries were used to facilitate delineation of park management zones (NPS 2020).

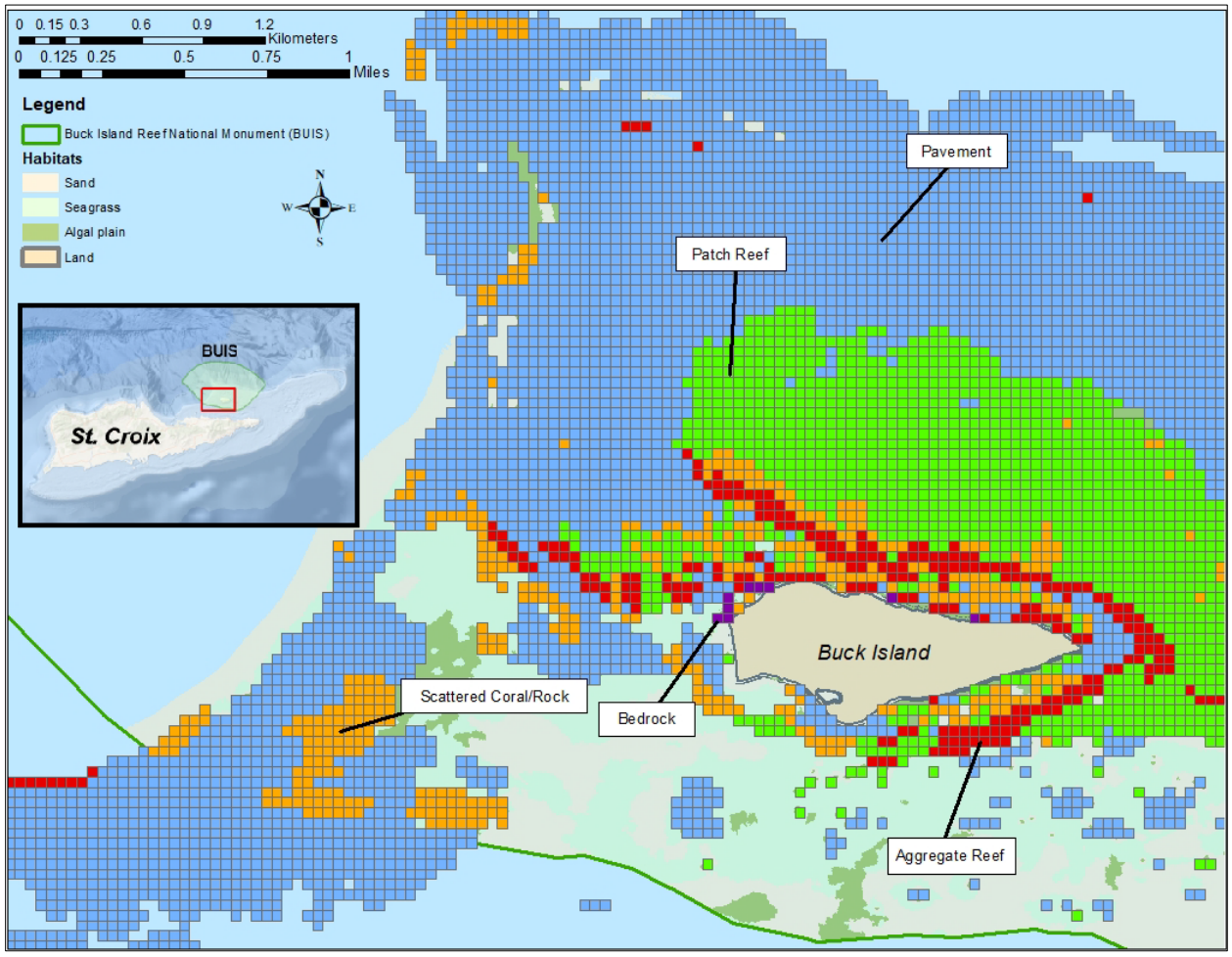


Figure 3. Cross shelf distribution of habitats in the St. Croix region within Buck Island Reef National Monument defined by the 50 × 50 meter (164 × 164 ft) primary sampling unit gridfile. The number of possible primary sample units (N_h) is calculated for each stratum within St. Croix and St. Thomas/St. John regions and is provided in Tables 4 and 5.

Grid cells

When constructing a sample frame, it is important that each independent unit represents the overall habitat contained in that unit. Since multiple habitat types may be present in any given sample unit, decision rules need to be applied that appropriately define the habitat. Bryan et al. (2013) considered, "majority," "hierarchical" and "composite" schemes to define the grid cell habitat type. They concluded the 5% minimum area value used for the hierarchical scheme likely overestimated the amount of higher priority habitat and may not be ideal for partitioning variance. Likewise, the majority area scheme likely underestimates high priority habitat while overestimating the amount of low complexity habitat. Thus, the composite rule method was selected for this protocol as the best fit of understanding the spatial distribution of habitat types and reef fish ecology. A cut off minimum of 10% hardbottom habitat within a primary sampling unit is required to define a grid as hardbottom. For cells with more than 10% hardbottom habitat, the composite rule (Table 1) is used to assign the class.

The conceptual layout of this one-stage stratified random sampling (StRS) design is shown (Figure 4), with survey design symbols and definitions also presented in Appendix A. For Florida, the details for the two-stage design used in previous surveys can be found in Brandt et al. (2009) and Smith et al. (2011a). However, going forward, the one-stage design applies to both Florida and the U.S Virgin Islands. With the variance of the second-stage sampling unit reduced to zero, the variance formula is effectively reduced to a single-stage design. The survey domain A is divided into h strata. Each stratum is further subdivided into primary sample units i, and each primary unit is again subdivided into secondary sample units j. Note that each primary and secondary sample unit contain a fixed amount of area; thus, the sum of second-stage sample units within primary units of all strata approximately equals the total area of the survey domain. Map resolution is such that the survey domain is divided into a grid with individual cells of size 50 meters × 50 meters (2,500 square meters [m^2]), and each cell is designated as belonging to a specific stratum (e.g., Figure 1). These grid cells are designated as ***primary sample units (PSU).*** The decision for grid size was based on map accuracy and requires secondary sampling within each primary unit to lower density variance. Primary sample units are further subdivided into 15-meter (49.2 ft) diameter visual census circular plots (176.7 square meters [1,902 square feet [ft^2]), sampled by divers, which are the ***secondary sample units (SSU).*** There is the equivalent of the area of fourteen secondary sampling units within each primary sampling unit. One sample, a pair of 15 meter diameter point counts, is selected and collected within each grid cell according to the procedures in SOP RF03 *Field Data Collection—Version 2.0* (SFCN 2025a). Thus, the physical survey footprint occupies a 30-meter (98.4 ft) wide area across the grid. For practical purposes a grid can accommodate one buddy pair of fish divers at a time given that the cylinders can be oriented in any direction from where the divers tie off the dive flag on the nearest hardbottom encountered. The paired point counts are representative of the habitat that is surveyed and are effective in characterizing the fish assemblage of the habitat yet small enough to minimize the chance of counting fish from an adjacent primary sampling unit. It is emphasized that the grid cell is simply used as a guide to sample a particular type of strata, but the actual "sampled stratum" is based on the environmental information collected by the diver at the location of the sample, irrespective of the target grid cell allocated in the sampling plan; i.e. the survey is not intended to characterize the grid cell.

NOAA's National Centers for Coastal Ocean Science, Center for Coastal Monitoring and Assessment, Biogeography Branch (NOAA-BB) created a gridded map in ArcGIS for the U.S Virgin Islands where each cell is assigned to a stratum. The grid was created by starting at the extent of the GIS shapefile (northwest of Puerto Rico) and rounding to 50 meters (164 ft). The grid was merged with existing benthic habitat maps (Kendall et al. 2001; Appendix B) to create a database file with the amount of each habitat type present per cell. The composite grid cell classification scheme calculations as described above were run using this database file to generate a single habitat classification for each grid cell. NOAA-BB then merged existing bathymetric layers to calculate an average depth for each cell and added this with the National Park Service boundaries (NPS 2020) to complete the 50-meter gridded layer. Grid cells were classified as marine if any portion of the grid cell was below water. Grid cells are assigned a management zone classification if any portion of a boundary is within a grid cell.

Similarly, UM-RSMAS merged this same information into gridded strata for the Florida Keys and the Tortugas. ArcGIS was used to delineate the survey domain into 50-meter gridded strata using the digital layers for the Unified Reef Map (FWC 2020b; Appendix A), depth (NGDC 1998; Taylor et al. 2018), FKNMS no-take marine reserve boundaries (FKNMS 2021) and National Park Service boundaries (NPS 2020). Additionally, a rugosity value was added to the Florida stratification in the 2020 revision of the grid to develop a refined benthic habitat map based on quantitative habitat metrics (Ault et al. 2020). The average vertical relief height (rugosity) was modeled by Vector Rugosity Measure (VRM) based on LIDAR mapping data and diver generated vertical relief data. The LIDAR data were gridded at 2 meters (6.6 ft), and the VRM was calculated for each 2 × 2-meter pixel; with a weighted average procedure applied to estimate the cell VRM value used in the regression for each 50-meter grid (Ault et al. 2020). However, diver collected data from previous RVCs proved more useful in predicting fish abundances (Ault et al. 2020), hence diver collected data is the primary source for rugosity and the VRM data is considered as a secondary source if needed. The total number of primary sampling units (N_h) in each stratum and areal coverage for Florida and the U.S. Virgin Islands are summarized in Tables 2 through 5. See Appendix C for additional tables with comparisons of total area (square meters) for mapped hardbottom and the sample domain.

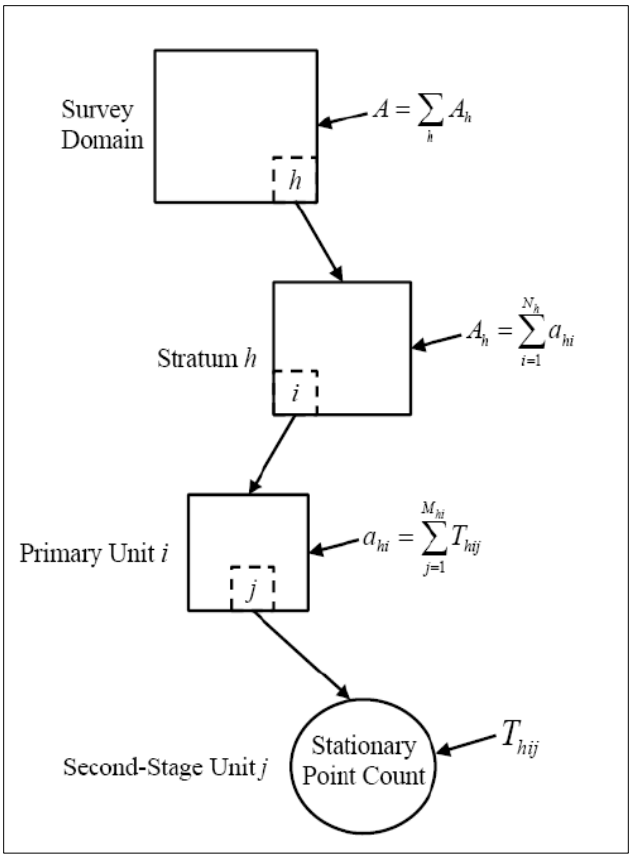


Figure 4. Conceptual diagram of the sampling domain and sample units for a one-stage stratified random survey design. Symbols are defined in Appendix C (From Brandt et al, 2009).

Table 2. Total possible primary units (N_h) in statistical strata defined by sub-region (e.g., Biscayne, Keys), cross-shelf zone, habitat class and depth, and management zone in the Florida Keys survey domain.

Stratum	Cross-Shelf Zone	Depth/Rugosity	Biscayne				Keys			
			# cells in park	area (km^2) in park	# cells in open	area (km^2) in open	# cells in protected	Area (km^2) in protected	# cells in open	area (km^2) in open
S01	Inshore Patch	Shallow/All relief	751	1.88	892	2.23	556	1.39	4,540	11.35
S02	Mid-channel Patch	Shallow/Low relief	13,634	34.09	1,774	4.44	200	0.50	9,625	24.06
S03	Mid-channel Patch	Shallow/High relief	3,677	9.19	128	0.32	78	0.20	935	2.34
S04	Mid-channel Patch	Shallow/Unknown	1,832	4.58	1	0.00	1,066	2.67	27,963	69.91
S05	Offshore Patch/Forereef	Shallow/Low relief	8,665	21.66	2,722	6.81	4,329	10.82	82,360	205.90
S06	Offshore Patch/Forereef	Shallow/High relief	4,352	10.88	1,296	3.24	2,179	5.45	12,644	31.61
S07	Offshore Patch/Forereef	Shallow/Unknown	1	0.00	91	0.23	888	2.22	10,102	25.26
S08	Offshore Patch/Forereef	Moderate/Low relief	1,689	4.22	961	2.40	404	1.01	6,740	16.85
S09	Offshore Patch/Forereef	Moderate/High relief	1,405	3.51	548	1.37	233	0.58	3,932	9.83
S10	Offshore Patch/Forereef	Moderate/Unknown	1,610	4.03	2,057	5.14	960	2.40	28,814	72.04
S11	Forereef	Deep/All relief	161	0.40	2,928	7.32	0	0.00	20,658	51.65
TOTAL	–	–	37,777	94.44	13,398	33.50	10,893	27.23	208,313	520.78

Table 3. Total possible primary units (N_h) in statistical strata defined by sub-region (Tortugas Bank and Dry Tortugas), habitat class, and management zone in the Tortugas subregion.

Stratum	Depth (m)	Rugosity (m)	DRTO Protected (RNA)		DRTO (park)		Outside DRTO		Tortugas Bank Protected (TNER)		Tortugas Bank Open	
			# cells	Area (km^2)	# cells	Area (km^2)	# cells	Area (km^2)	# cells	Area (km^2)	# cells	Area (km^2)
T01	<12	<0.26	3,825	9.56	10,207	25.52	0	0.00	0	0.00	0	0.00
T02	<12	>0.26	5,488	13.72	6,309	15.77	0	0.00	0	0.00	0	0.00
T03	<12	unknown	590	1.48	1,607	4.02	67	0.17	0	0.00	0	0.00
T04	12–21.9	<0.26	10,097	25.24	7,248	18.12	2,061	5.15	5,441	13.60	7,001	17.50
T05	12–21.9	>0.26	4,219	10.55	2,364	5.91	585	1.46	7,727	19.32	6,214	15.54
T06	12–21.9	Unknown	1,823	4.56	1,359	3.40	7,368	18.42	0	0.00	0	0.00
T07	22–33	<0.26	0	0.00	0	0.00	0	0.00	5,740	14.35	8,323	20.81
T08	22–33	>0.26	0	0.00	0	0.00	0	0.00	8,633	21.58	1,449	3.62
T09	22–33	unknown	1,681	4.20	880	2.20	2,631	6.58	3,292	8.23	157	0.39
TOTAL	–	–	27,723	69.31	29,974	74.94	12,712	31.78	30,833	77.08	23,144	57.86

Table 4. Total possible primary units (N_h) in statistical strata defined for the St. Thomas/St. John region habitat class, depth and management zone (Protected, Open) in the United States Virgin Islands.

Depth, Habitat	VIIS		VICR		STEER		Open	
	# cells	Area (km^2)	# cells	Area (km^2)	# cells	Area (km^2)	# cells	Area (km^2)
Shallow, Bedrock	377	0.94	63	0.16	254	0.64	2,832	7.08
Deep, Aggregate Reef	359	0.90	175	0.44	122	0.31	2,678	6.70
Deep, Hard	982	2.46	493	1.23	0	0.00	17,233	43.08
Deep, Patch Reef	182	0.46	182	0.46	49	0.12	1,105	2.76
Deep, Pavement	790	1.98	807	2.02	153	0.38	9,423	23.56
Deep, Scattered Coral/Rock	67	0.17	79	0.20	26	0.07	2,332	5.83
Shallow, Aggregate Reef	383	0.96	110	0.28	252	0.63	1,687	4.22
Shallow, Hard	24	0.06	0	0.00	0	0.00	241	0.60
Shallow, Patch Reef	122	0.31	45	0.11	84	0.21	171	0.43
Shallow, Pavement	1,180	2.95	90	0.23	332	0.83	3,852	9.63
Shallow, Scattered Coral/Rock	248	0.62	44	0.11	101	0.25	736	1.84
TOTAL	4,714	11.79	2,088	5.22	1,373	3.43	42,290	105.73

Table 5. Total possible primary units (N_h) in statistical strata defined for the St. Croix region habitat class, depth and management zone (Protected, Open) in the United States Virgin Islands.

Depth, Habitat	BUIS		SARI		EEMP		Open	
	# cells	Area (km^2)	# cells	Area (km^2)	# cells	Area (km^2)	# cells	Area (km^2)
Shallow, Bedrock	9	0.02	31	0.08	304	0.76	891	2.23
Deep, Aggregate Reef	18	0.05	19	0.05	449	1.12	2,101	5.25
Deep, Hard	0	0.00	3	0.01	33	0.08	1,231	3.08
Deep, Patch Reef	649	1.62	0	0.00	191	0.48	256	0.64
Deep, Pavement	1,785	4.46	80	0.20	22,956	57.39	28,217	70.54
Deep, Scattered Coral/Rock	161	0.40	8	0.02	2,361	5.90	3,270	8.18
Shallow, Aggregate Reef	223	0.56	46	0.12	1,120	2.80	1,235	3.09
Shallow, Hard	0	0.00	4	0.01	0	0.00	95	0.24
Shallow, Patch Reef	1,012	2.53	4	0.01	179	0.45	613	1.53
Shallow, Pavement	3,196	7.99	305	0.76	4,883	12.21	13,637	34.09
Shallow, Scattered Coral/Rock	381	0.95	0	0.00	245	0.61	495	1.24
TOTAL	7,434	18.59	500	1.25	32,721	81.80	52,041	130.10

Modifying and Maintaining the Grid Cell Layer

In addition to statistical and ecological benefits, a sample frame composed of independent grids is also advantageous through its flexibility in adapting to changes and upgrades in benthic data. Improvements in habitat maps or bathymetry should be incorporated into classified grids and the current classification scheme should be re-run when new information is available. Any change to the underlying grid and strata will affect strata-level weighting factors and has implications for interpreting historical data. A change in the grid scheme necessitates re-calculation of historic population metrics with updated strata weights to prevent any false trends. The new map is used to improve the area calculations of the historic strata with the estimates re-run with the new areas, i.e. the historic data should **not** be post-stratified to the new strata. The grid layer, bathymetric layers and benthic habitat maps should all be maintained by a single agency (NOAA at present) but available to all partners. The South Florida/Caribbean Network and all partners receive a copy of the most recent *Ntot* file for the season from which to run analyses. If additional areas are added to the grid in the future, the procedures described above is followed for the new areas.

Sample Allocation

The one-stage stratified random design increases the efficiency of sampling by effectively stratifying the entire domain based on variables (e.g., habitat characteristics, rugosity, depth, and management) that influence the variability of fish population densities. With this stratification scheme in place, the sample size necessary to achieve a specified level of precision can be calculated based on existing data. This type of allocation scheme is termed a Neyman (or optimum) allocation scheme (Cochran 1977) and it is used to determine the number of ***primary units*** to be sampled within each stratum to achieve a given precision. The stratification scheme partitions the survey into subregions of low, moderate and high variance. While the allocation scheme based on stratum size and variance places more samples in larger strata and higher variance strata.

First, the total number of primary units required to achieve a specified variance under an optimal allocation scheme, n^*, is calculated for each species. Derived from Cochran (1977), this optimal allocation of primary units for a given target variance, V, of fish density, $\overline{D}_{st}$(individuals m^{-2}), is calculated as:

$$n^* = \frac{\left(\sum_h w_h s_h\right)^2}{V\left(\overline{D}_{st}\right) + \frac{1}{N}\sum_h w_h s_h^2}$$

SOP RF01.1

In equation SOP RF01.1, s_h^2 is the sample variance in stratum h and s_h is the standard deviation for each species in stratum h. The second-stage variance term drops out in a single-stage design which is explained further in SOP RF05 *Data Analyses and Reporting—Version 1.1* (SFCN 2025b). See Smith et al. (2011a) and Brandt et al. (2009) for additional details on the two-stage design formulas.

$$\overline{D}_h = \frac{1}{n_h}\sum_j D_{hj}$$ SOP RF01.2

$$s_h^2 = \frac{1}{n_h - 1}\sum_{j=1}^{n_h}\left(D_{hj} - \overline{D_h}\right)^2$$ SOP RF01.3

Where $\overline{D}_h$ is mean density in stratum h, and D_{hj} is density in second-stage unit j in stratum h, and n_h is the number of primary units sampled in stratum h.

Also, in equation RF01.1, s_h is the sample standard deviation in stratum h:

$$s_h = \sqrt{s_h^2}$$ SOP RF01.4

and w_h is the weighting factor for each stratum, calculated as its proportion of the overall survey domain (or sampling frame) where N_h is the total possible number of primary units in stratum h based on its total area:

$$w_h = \frac{N_h}{\sum_h N_h}$$ SOP RF01.5

and

$$\overline{D}_{st} = \sum_h \left(w_h \overline{D_h}\right)$$ SOP RF01.6

The optimal number of second-stage units (m^*_h) was estimated (not calculated) as 2 for the historical Florida data (1998–2018). However, with the reduction in primary unit size to 50 × 50 meters (164 × 164 ft), this value for 2020 surveys and later in Florida and all surveys in the U.S. Virgin Islands will be estimated (not calculated) as 1 and was used in all calculations of n^*. The target variance for a given species ($V[\overline{D}_{st}]$ in Equation RF01.1) is calculated based on a target coefficient of variation (CV), which is an expressed standard measure of performance (Cochran 1977). The CV of a sample is the standard error expressed as a proportion (or percentage) of the mean:

$$CV[\overline{y}_{st}] = \frac{SE[\overline{y}_{st}]}{\overline{y}_{st}}$$ SOP RF01.7

Since the 95% confidence interval for a population metric is approximately two standard errors above and below the mean, the ability to statistically detect a difference translates to approximately ± 2 times the CV. Therefore, if mean fish density in a sub-region has a CV of 50%, then a 100% change in the population, or a doubling of the population, can be detected.

In calculations of the target variance for fish density under this design, $\overline{D}_{st}$ is used as $\overline{y}_{st}$ in Equation RF01.7, which is mean fish density under a stratified design. Using a target CV, the target variance in Equation RF01.1 is:

$$V\left[\overline{D}_{st}\right] = \left(CV\left[\overline{D}_{st}\right] * \overline{D}_{st}\right)^2 \qquad \text{SOP RF01.8}$$

The optimal number or Neyman allocation of primary units to sample in stratum h is:

$$n_h = n^* \cdot \left(\frac{w_h s_h}{\sum_h w_h s_h}\right) \qquad \text{SOP RF01.9}$$

These calculations are made for multiple levels of desired variance for each species. They are then compared among species and with the total capacity of the cooperative sampling group. A final target n^* is chosen that will accomplish the best possible balance between achievable precision for the greatest number of exploited species and the capabilities of the agencies. All variable names and equations are also listed in Appendix A.

The main steps in the allocation process include the following:

1. Within the spatial framework of the domain (Florida or USVI), the allocation strata are identified. These strata are the main stratification variables. For Florida, these include zone, depth, and rugosity and for the U.S Virgin Islands include habitat and depth. Subregions and management area are not included in this total allocation step but are incorporated later in the process when evaluation of these sub areas is required.

2. Identify the focal fish species (see narrative). These were chosen based on input from all science partners, include species with 20–70% frequency of occurrence, include various sizes, territory areas and behaviors and are all economically and ecological important.

3. Generate stratum mean density and weighted variance estimates for allocation strata for these species. For stratification, this protocol currently focuses on habitat and depth in the U.S Virgin Islands and rugosity and depth in Florida, but there may be better ways to partition variance that could be used.

4. Conduct performance analysis to generate *CV* vs. n^* to determine target sample size and target level of precision. Often the target sample size for the upcoming survey is predetermined by the resources available. In this case the *CV* vs. n^* provide the predicted performance of each species, given the target effort. This is where we set the *CV*, which usually ranges from 10–20%. An example worksheet is presented below in Table 6. The first step is to determine the total possible number of secondary samples in each strata (*ntot*) and the weighting factor (w_h) is based on the total possible number of primary units in stratum *h* over the total. Weighted density, variance and standard deviation are determined by multiplying the respective strata average by the weighting factor. These values are then summed for the n^* calculation after a target *CV* has been identified (example *CV* = 15%). This step is repeated for each target species.

Table 6. Example of post stratification analysis to determine the target sample size and target level of precision for a single species, Blue Tang, where *N* = Total number of possible samples, *V* = target variance. [A]Shaded area indicates sum (∑) values used in the n* calculation.

Species	Stratum (h)	Total possible primary samples (ntot)	Weighting factor (Wh)	Stratum average density (AvD)	Stratum variance (S^2)	Stratum standard deviation (S)	Wh*AvD	Wh*S^2	Wh*S
Blue Tang	D5	1895	0.0714	2.29375	6.747	2.597	0.1638	0.4817	0.1855
–	D6	8366	0.3152	3.04416	11.614	3.408	0.9595	3.6607	1.0742
–	D8	1239	0.0467	4.5	11.583	3.403	0.2102	0.5409	0.1589
–	D9	3953	0.1489	2.29375	6.747	2.597	0.3415	1.0046	0.3868
–	S5	1036	0.039	2.83586	12.392	3.520	0.1106	0.4833	0.1373
–	S6	5441	0.205	4.57519	23.488	4.846	0.9379	4.8150	0.9935
–	S7	1978	0.0745	7.45	63.4	7.962	0.5550	4.7233	0.5932
–	S8	421	0.0159	3.40865	21.954	4.686	0.0542	0.3491	0.0745
–	S9	2215	0.0834	8.21542	248.111	15.752	0.6852	20.6925	1.3137
–	–	***N***	–	–	–	–	**Avg Density**	**Variance**	**Std Dev**
–	**Sum[A]**	**26544[A]**	–	–	–	–	**4.0179[A]**	**36.7512[A]**	**4.9175[A]**
–	–	**? CV 15%**	**V = (.15 * AvD)^2**	**= 0.3632**	**–**	–	–	–	–
–	–	**n* = (Standard Deviation)^2**		**= 66.5**	–	–	–	–	–
–	–	***V* + Variance/*N***		–	–	–	–	–	–

5. Determine how many samples should go within each stratum from the total target effort (e.g. 400 in Dry Tortugas for 2021) using the optimal or Neyman allocation (Equation SOP RF01.9). This process represents a composite Neyman allocation because all target species are included to determine a final number per strata. A proportional allocation could also be used (size of stratum only considered; Equation SOP RF1.10). The total number of sites to be surveyed per stratum is the result of this step.

$$n_h = n(w_h) \qquad \text{SOP RF1.10}$$

6. The sites to be surveyed per allocation stratum are then suballocated proportionally to each subregion and MPA using size of the stratum only. Given the collective protected areas in the Florida Keys are small, the minimal allocation is set at two PSUs. The suballocation ensures a good spatial distribution of PSUs. In addition, the suballocation allows the user to split apart the allocation strata for analysis which is necessary for reporting in some cases and for some partners.

7. Finally, random PSUs (sites) are selected for each stratum, subregion, and management type (open or protected)—the result of the suballocation.

Sample Unit (Location) Selection

Once the total number of primary units to be sampled is determined, the actual random selection of sites is carried out in two steps. First, the primary units *i* to be sampled per stratum are randomly selected from the complete list of N_h units within a stratum using a discrete uniform probability distribution, which assigns equal selection probability to each primary unit (Law 2007), or in other words, we are randomly selecting locations off a grid of points. Then in the field, one second-stage unit *j* is chosen from the total possible second stage units within a primary sampling unit. The probability of selection of the nearest habitat to the centroid is not necessarily known, but we know that the survey design allows us to detect change without depending on the validity of a presumptive relationship or model (Hansen 1987). This is typically done by navigating to the centroid of the grid cell to deploy divers, but if no hard bottom is present according to the boat's sonar at the centroid, the boat may navigate within the confines of the cell until hard bottom is detected by the sonar, then deploy divers. Divers survey the first habitat encountered below them but may swim to appropriate hardbottom habitat within their visible range if necessary (see SOP RF03 *Field Data Collection—Version 2.0* [SFCN 2025a]). In concern for dive safety and because of possible spatial autocorrelation, a diver station (i.e., second-stage unit) consists of the ***average of combined stationary point count (RVC) estimates from the buddy pair*** for each metric recorded. Therefore, the diver station (i.e., second-stage unit) is sampled by two individual divers (i.e., a buddy pair), for a total of two scientific dives within each primary unit (i.e. one second-stage unit sampled) under normal operations.

In theory, the selection of a secondary stage unit within each primary unit should be random, but this is not feasible in the field without dropping a weighted reel on habitats. This approach is not possible

due to the presence of threatened and endangered coral species and in general the possibility of causing damage to delicate corals. In practice, deploying divers on the intended hard-bottom habitat can be logistically difficult. In part, this is due to map resolution and accuracy. GPS error, currents, wind, and depth of the site can complicate the issue. Furthermore, once deployed, the divers do not know their exact location because GPS does not work underwater. In the USVI, the random selection of points within mapped polygons (Menza et al. 2006) or the center of the grid (Bryan et al. 2013) combined with random selection of transect survey direction resulted in surveys off of targeted habitats and often not at the actual randomized location (Ruttenberg and Feeley pers. comm.). The mean distance from the centroid to the center of the paired fish surveys (SSU) during 2017 and 2019 USVI surveys was 24.1 ± 0.7 m (mean ± SE; Figure 5). The scale of the combined secondary point counts within the grid (2 x 15 m diameter surveys) necessitates the placement of stationary cylinders near the primary unit center to fit within the 50 × 50 meters (2,500 m^2) primary sampling unit itself. The majority (73%) of the paired SSU center points in the USVI surveys fell within the primary sampling unit. Factors such as positional GPS error, navigational error (human), wind, currents, deployment delays and depth contributed to surveys placed outside the targeted grid cell area.

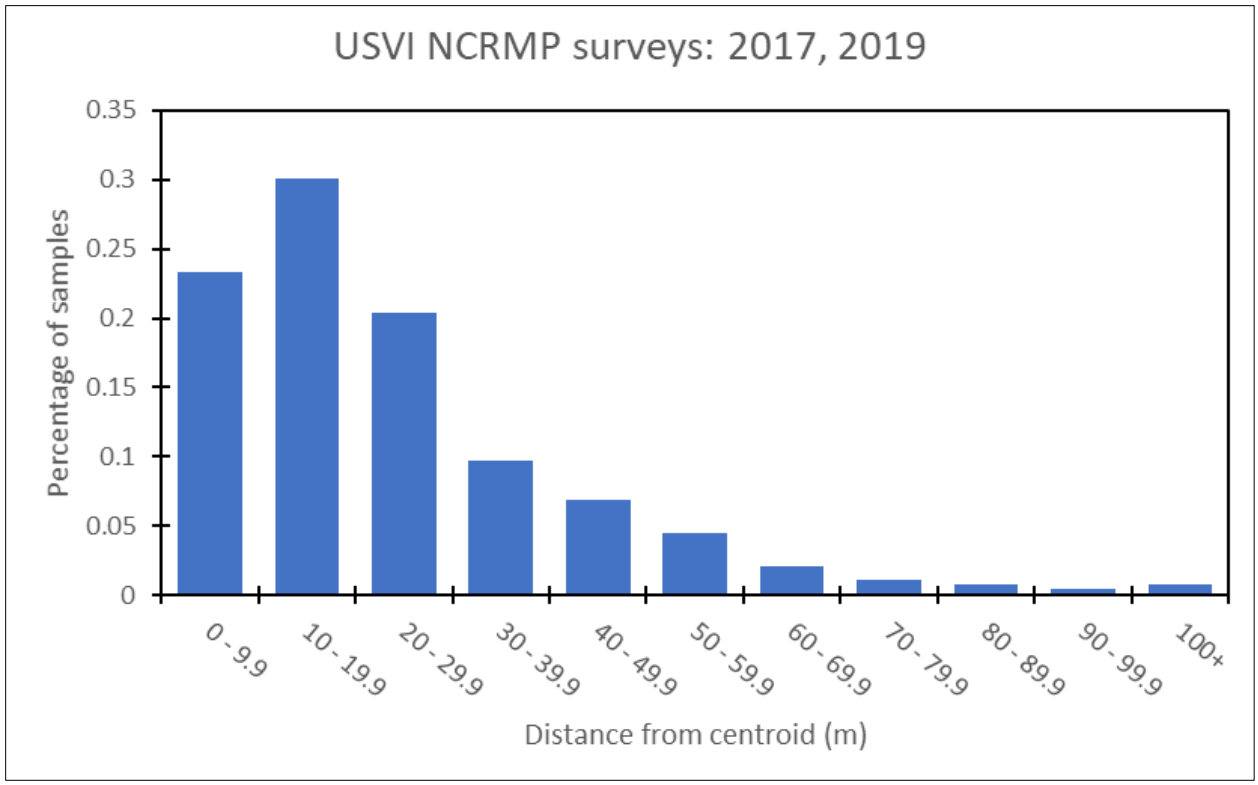


Figure 5. Distance of the center of paired second-stage unit surveys (n = 982; range 0.1–198.8 meters [652.2 ft]) from the primary unit centroid during St. Croix and St. Thomas/St. John, USVI fish surveys (2017 and 2019).

Sample Optimization

Reef fish populations are highly variable among species and within species among life history stages. Therefore, calculations of optimum sample size need to be made independently by species and life stage, and by accounting for the historical sampling design used to collect the data as well as the established and possible future goals of each targeted area in question. The sampling performance analysis (n^*) is a best estimate based on the present state of the science, but by no means should it be treated as a constant to be used for all future surveys. Optimal sampling allocation must be recalculated iteratively and consider acquired new knowledge of the system, future data, and/or improved stratification methods. Other metrics used to measure ecosystem health such as species richness and diversity typically have low variances and if sample effort is optimized towards individual species, the precision to detect change for these metrics is usually very high (Bryan et al. 2013).

Prior to each survey, the chief analyst needs to meet with representatives from each collaborating agency to determine the number of grid cells that will be sampled. To aid in this discussion, the analyst provides n^* values for CV's of 15% and 20% based on the current stratification scheme and data on optimization species from past surveys. Graphs depicting CV values over a range of sampling effort (n^* curves) will aid with decisions on effort for each region and management zone. Calculations are made for multiple levels of desired variance for each species. They are then viewed among species but also within the context of the total capacity of the agencies cooperating to conduct sampling. Budget and needs for target levels of precision can be used to determine appropriate sampling effort and the overall number of grid cells to be sampled. It is important to note that the estimated number of sites necessary to achieve a desired level of precision can fluctuate between surveys and that allocation must be revisited prior to each survey. A balance of the CV values for each species inside and outside management zones is strived for during allocation since comparisons are made at the lowest level of precision between the two zones. A final target n^* is chosen that will accomplish the best possible balance between achievable precision for the greatest number of target species and agency capabilities. It is possible that strata with low proportions of total habitat and/or low variance may have no samples allocated by the optimal distribution formula under a given effort. In these circumstances it is important that a minimum of two samples are allocated to that stratum to allow for variance calculations. Estimation of variance with only two samples is suboptimal and should be avoided if possible during the survey allocation.

A table including optimal allocation values for all species by stratum can be constructed to aid in the decision process by the chief analyst. Effort is shown as a percentage of total effort for that management zone. The percentage of each stratum in the management zone is also shown as a reference. A proportional allocation of effort would follow these values and comparing individual optimal allocation to proportional allows the analyst to see which strata require over- or under-sampling. Because sampling targets multiple species, the most efficient sampling strategy for one species may not necessarily be the most efficient for the others. So, in practice the decision on allocation between strata must be a compromise between the optimal allocation for each species and an overall allocation to balance effort and performance across the region and all management zones.

NOAA's National Centers for Coastal Ocean Science, Center for Coastal Monitoring and Assessment, Biogeography Branch's (BB) ArcGIS site selection tool is used to randomly select the grid cells to be sampled (NCCOS 2020). The GPS coordinates for the center of each grid cell to be sampled are then generated. A table with the number of sites allocated to each stratum by zone (management or outside) is then created. The chief analyst produces and distributes the list of randomly chosen survey sites for within and outside of each management zone for each region two weeks prior to the survey using the optimal allocation method. Each collaborating agency will then indicate which sites they will be responsible for surveying.

Procedure for Selecting Random Sample Sites (grid cells) United States Virgin Islands—NOAA Sampling Design Tool

Open the NOAA Sampling Design Tool within ArcGIS. If necessary, the tool can be downloaded and installed from the NOAA website (https://coastalscience.noaa.gov/projects/detail?key=185).

1. Within the "Sampling Design Tool" window:
    a. Under "Sampling type", choose "Select Samples from Frame."
    b. Under "Sampling design", Choose "Stratified Random."
    c. Check the "Export selected features" box.
    d. Note: This will export a shapefile of the random sample sites to the location chosen in step 3.g. below.
    e. In "Sample frame," select the grid shapefile from which the random sample sites will be drawn.
    f. Under "Strata field," select the field in the attribute table containing the strata of interest.
    g. Click "Run."
2. Within the "Select Stratified Inputs" window:
    a. Under "Allocation Method," click on the "Even" button.
    b. In the "Sample units to allocate" box, enter the total number of samples desired.
    c. Note: This will evenly allocate samples within each stratum. The "Define the number of sample units to select in each stratum" window will show the number of samples allocated in each stratum. If a different number of samples is desired per stratum (i.e. for an optimal allocation), this may be entered manually in the "# of samples" column.
    d. Do not check the "Keep minimum distance between points" box.

e. Click “Run.”

f. In the “Save a feature class” window, navigate to the location where the shapefile of the random sample sites will be exported.

g. Under “Name:” type an appropriate name for the shapefile.

h. Under “Save as type:” select “Feature classes.”

3. Click “Save.”

Procedure for Selecting Random Sample Sites (grid cells) Florida

PSUs within each stratum are randomly selected from the complete list of PSUs (all grid cells within the sampling domain) using a uniform distribution with equal probability of selection (Law 2007). In practice, this random selection procedure uses the sampling grid file, a file that identifies the number of PSUs to be sampled for each stratum, and R to generate a list of PSUs or grid cells to be sampled. The previous described iterative process of the n^* calculation incorporates the allocations per stratum (see *Sample Allocation* section above). A complete list is generated for the primary list and the alternate list.

Design Performance Analysis

An analysis of the performance of the sampling allocation is completed after each season. This analysis aids in determining sampling allocation for the subsequent year. The performance of a sampling design is ultimately the result of trade-offs between the cost of surveying (usually measured by the number of samples) and the precision of population estimates. The performance measure that is typically used by this program is the coefficient of variation (CV), which is defined and discussed above.

Florida Keys and Tortugas

The suggested analyses focus on six important species of reef fish commonly targeted by commercial and recreational fisheries on Florida Keys reefs: Hogfish (*Lachnolaimus maximus*), Mutton Snapper (*Lutjanus analis*), Gray Snapper (*Lutjanus griseus*), Yellowtail Snapper (*Ocyurus chrysurus*), Red Grouper (*Epinephelus morio*), and Black Grouper (*Mycteroperca bonaci*). Because these species are known to exhibit habitat-specificity based on life stage which may influence their abundances across spatial gradients, each analysis may be done separately by life stage (juveniles and adults). The current sampling allocation strategy is targeted towards these species because of their economic importance. However, these species are found in relatively low abundance throughout the Keys region and are considered overfished (Ault et al. 2005). Therefore, if a sampling strategy is doing an adequate job of sampling for these low-abundance species, it is also likely doing an adequate job of sampling for other, more abundant, species such as the major herbivorous fish groups (e.g., parrotfishes, surgeonfishes) that may be important ecologically but not necessarily economically.

Below are the results of a performance analysis of reef fish sample data taken in the Florida Keys and the Tortugas regions, which is then used to calculate n^*. The analysis also focused on calculating n^* for managed areas within the Florida Keys and the Tortugas including Biscayne NP, Dry Tortugas

NP, Tortugas RNA and the Tortugas North ER with the goal of detecting differences in relative fish density for targeted species among years. To do this, sample data from region-wide annual sampling between 2014, 2016 and 2018 were analyzed using equations SOP RF01.1 and SOP RF01.9, with area defined by defined region or managed zone for the analyses. Results are presented in tables with n^* values for specified CV values, and CV versus n^* graphs that provide a measure of additional or less survey effort needed to achieve a desired CV for all fish (juveniles and adults) by species (Figure 6 and 7). These calculations were compared with the number of primary units sampled in previous surveys (Tables 6–8). Results are also presented by life stage for Red Grouper, Black Grouper, Mutton Snapper and Yellowtail Snapper for the Florida Keys and Tortugas regions (Figures 8 and 9). It may be of interest to evaluate design performance based on life stage for some individual species. Black Grouper is an example of an exploited species of great commercial and recreational interest that has a relatively large size at maturity (and length of capture in Florida) but may recruit to patch reefs and offshore reefs as a juvenile. All comparisons were made using a one stage design, despite two SSUs historically collected, since future surveys will routinely consist of one set of paired surveys (one SSU).

Examination of Table 7 and the n^* graphs (Figures 5 and 6) for each of the six focal species shows that additional sampling will lead to negligible gains in precision across both the Florida Keys and the Tortugas. All focal species in the Florida Keys are expected to be between 15–20% CVs if historical sampling effort is achieved (n = 450). For the Tortugas region, performance results exceed precision in the Florida Keys, with four of six focal species expected to have 10% CVs assuming an historical sampling effort (n = 400). For perspective, a more ubiquitous species such as *Thalassoma bifasciatum*, Bluehead, is expected to reach a CV of 5% at 175 and 197 surveys in the Tortugas and Florida Keys respectively and precision gains are negligible with additional surveys (flat part of the n^* curve). In the Tortugas protected areas, four of six focal species are expected to be between 15–20% CVs with past sampling effort (TNER n = 90, DTNP RNA = 100, DRTO OPEN = 100; Table 8). Gray Snapper and Black Grouper CVs were slightly higher in the Tortugas North ER and the Dry Tortugas NP Open. Even a small amount of additional sampling in each of these areas would increase precision for these species (except Gray Snapper DRTO OPEN) but is probably not practical within the greater Tortugas survey mission (Table 8). Focal species in the Florida Keys protected areas are expected to be close to or better than a 20% CV with an historical allocation of 120 surveys (Table 9). Within Biscayne NP, although current sampling is fairly precise for Hogfish and Yellowtail Snapper (≤ 20% CV), an increase in sampling effort from 120 to 150 surveys is expected to result in an improvement in the precision estimates of relative density for the other focal species except Black Grouper. There are so few Black Grouper remaining in the Biscayne NP, that attaining similar precision in the survey is unrealistic (n = 481). However, with 150 surveys within Biscayne NP the expected CV is approximately 35% for Black Grouper, which still provides the ability to detect a 70% change in relative density for this species.

Sampling in Biscayne NP is a combined effort between NOAA SEFSC, UM-RSMAS, South Florida/ Caribbean Network and Biscayne NP. In 2018, 120 primary units were sampled in a two-stage sampling unit design. Approximately six sites were completed per boat per day in Biscayne NP (12 sites per day by two independent dive teams) over 10–12 days. If an additional one site per boat can

be completed in a single secondary unit design (Biscayne NP 2020 fieldwork, Vanessa McDonough pers. comm.), this will result in approximately 150 primary units sampled in the same number of days (10–12 days). Therefore, the comparison of current CV achieved with potential CV is attainable based on a similar number of days effort. Annual survey effort in the Biscayne NP area has been traditionally lower, but with the recent (2020) state of Florida fisheries management actions within the park, as part of the park's Fishery Science Plan (McDonough et al. 2019), a concerted effort has been made to increase the number of surveys within the park and improve the precision of relative density estimates.

Table 7. Predicted survey effort needed to achieve coefficient of variation (CV) values for focal species in the Florida Keys and Tortugas sub regions based on one-stage stratified random survey effort from 2014, 2016 and 2018. [A] Green shading indicates expected CVs based on approximate historical targeted allocations (Florida Keys n = 480; Tortugas n = 400).

Common name	Code	Florida Keys (All)				All Tortugas			
		n*20	n*15	n*10	n*5	n*20	n*15	n*10	n*5
Black Grouper	MYC BONA	160[A]	284[A]	636	2451	142[A]	250[A]	553	2022
Gray Snapper	LUT GRIS	195[A]	344[A]	762	2812	373[A]	650	1386	4321
Hogfish	LAC MAXI	34[A]	61[A]	136[A]	542	40[A]	71[A]	15[A]	627
Mutton Snapper	LUT ANAL	87[A]	154[A]	346[A]	1361	56[A]	99[A]	222[A]	869
Red Grouper	EPI MORI	143[A]	253[A]	566	2193	22[A]	40[A]	89[A]	354[A]
Yellowtail Snapper	OCY CHRY	131[A]	233[A]	522	2033	45[A]	79[A]	178[A]	691

Table 8. Predicted survey effort needed to achieve coefficient of variation (CV) values for focal species in the Tortugas North Ecological Reserve (TNER), Research Natural Area (RNA) and Dry Tortugas National Park (DRTO), based on one-stage stratified random survey effort from 2014, 2016 and 2018. [A] Green shading indicates expected CVs based on approximate historical targeted allocations (TNER n = 90; RNA n = 100; DRTO – OPEN n = 100).

Common name	Code	TNER				RNA				DRTO - OPEN			
		n*20	n*15	n*10	n*5	n*20	n*15	n*10	n*5	n*20	n*15	n*10	n*5
Black Grouper	MYC BONA	122	209	426	1136	128	224	477	1489	165	290	632	2140
Gray Snapper	LUT GRIS	130	224	460	1254	75 [A]	131	283	923	430	742	1542	4370
Hogfish	LAC MAXI	36[A]	64 [A]	142	538	44 [A]	79 [A]	174	636	46 [A]	81 [A]	182	703
Mutton Snapper	LUT ANAL	60 [A]	105	233	853	39 [A]	69 [A]	152	562	60 [A]	107 [A]	238	911
Red Grouper	EPI MORI	19 [A]	34 [A]	77 [A]	298	30 [A]	53 [A]	117	441	24 [A]	42 [A]	95 [A]	374
Yellowtail Snapper	OCY CHRY	41 [A]	73 [A]	162	598	29 [A]	52 [A]	116	437	51 [A]	91 [A]	203	777

Table 9. Predicted survey effort needed to achieve coefficient of variation (CV) values for focal species in the Biscayne National Park (BISC) and Florida Keys protected areas based on one-stage stratified random survey effort from 2014, 2016 and 2018. [A] Green shading indicates expected CVs based on approximate historical targeted allocations (BISC and FK Protected areas, n = 120).

Common name	Code	BISC				Florida Keys (protected areas)			
		n*20	n*15	n*10	n*5	n*20	n*15	n*10	n*5
Black Grouper	MYC BONA	481	829	1716	4805	84 [A]	144	301	859
Gray Snapper	LUT GRIS	142	250	542	1820	128	218	443	1160
Hogfish	LAC MAXI	30 [A]	53 [A]	119 [A]	460	38 [A]	67 [A]	146	493
Mutton Snapper	LUT ANAL	125	220	484	1718	78 [A]	135	282	821
Red Grouper	EPI MORI	150	264	577	2007	96 [A]	166	346	991
Yellowtail Snapper	OCY CHRY	52 [A]	91 [A]	204	775	45 [A]	79 [A]	173	581

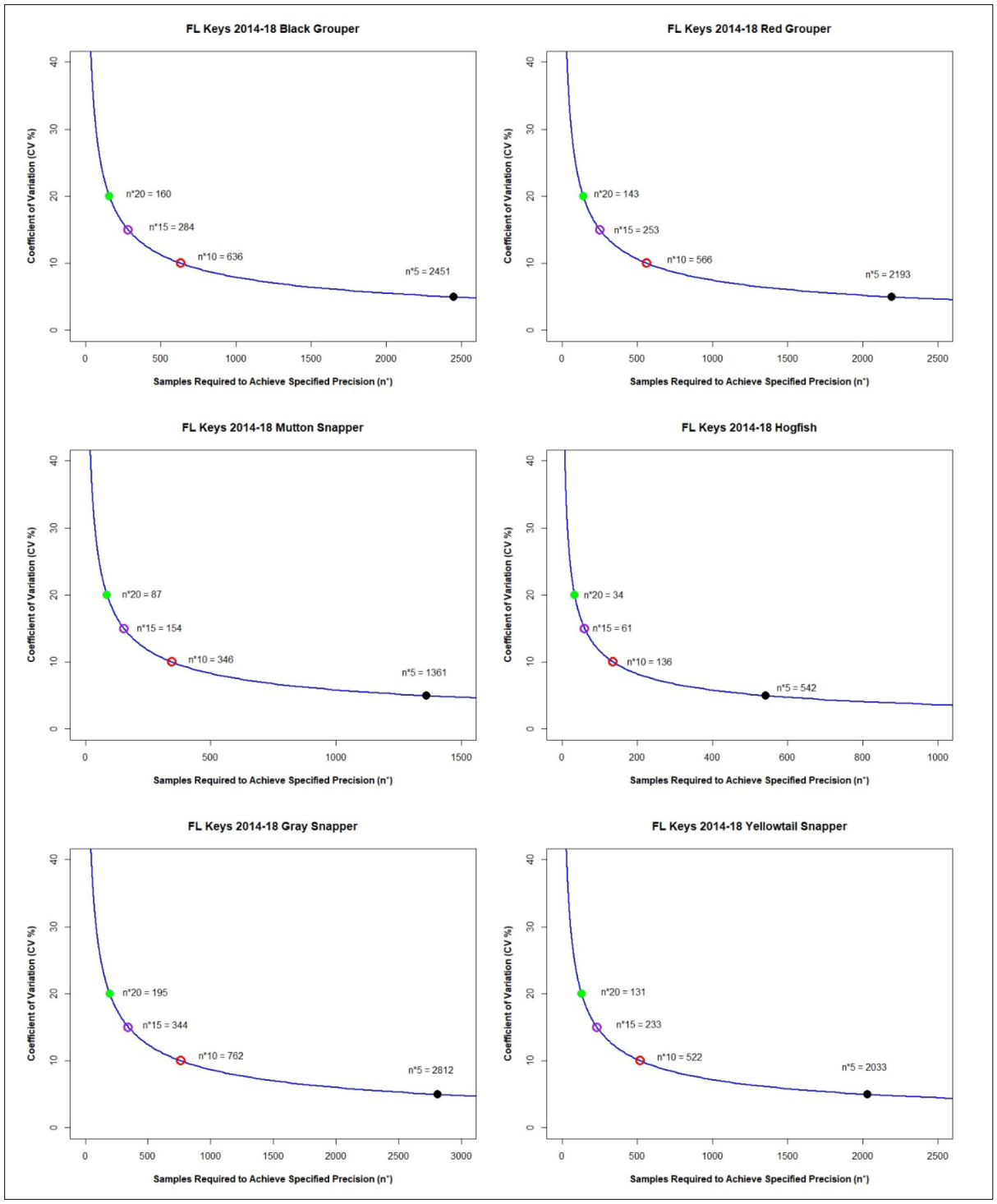


Figure 6. Performance (n*) curves for 6 focal species in the Florida Keys subregion. Based on one-stage stratified random surveys with expected CV values achieved by sampling effort based on 2014, 2016 and 2018 survey data. The sample sizes required to achieve a precision of 5, 10, 15, and 20% CV are also indicated.

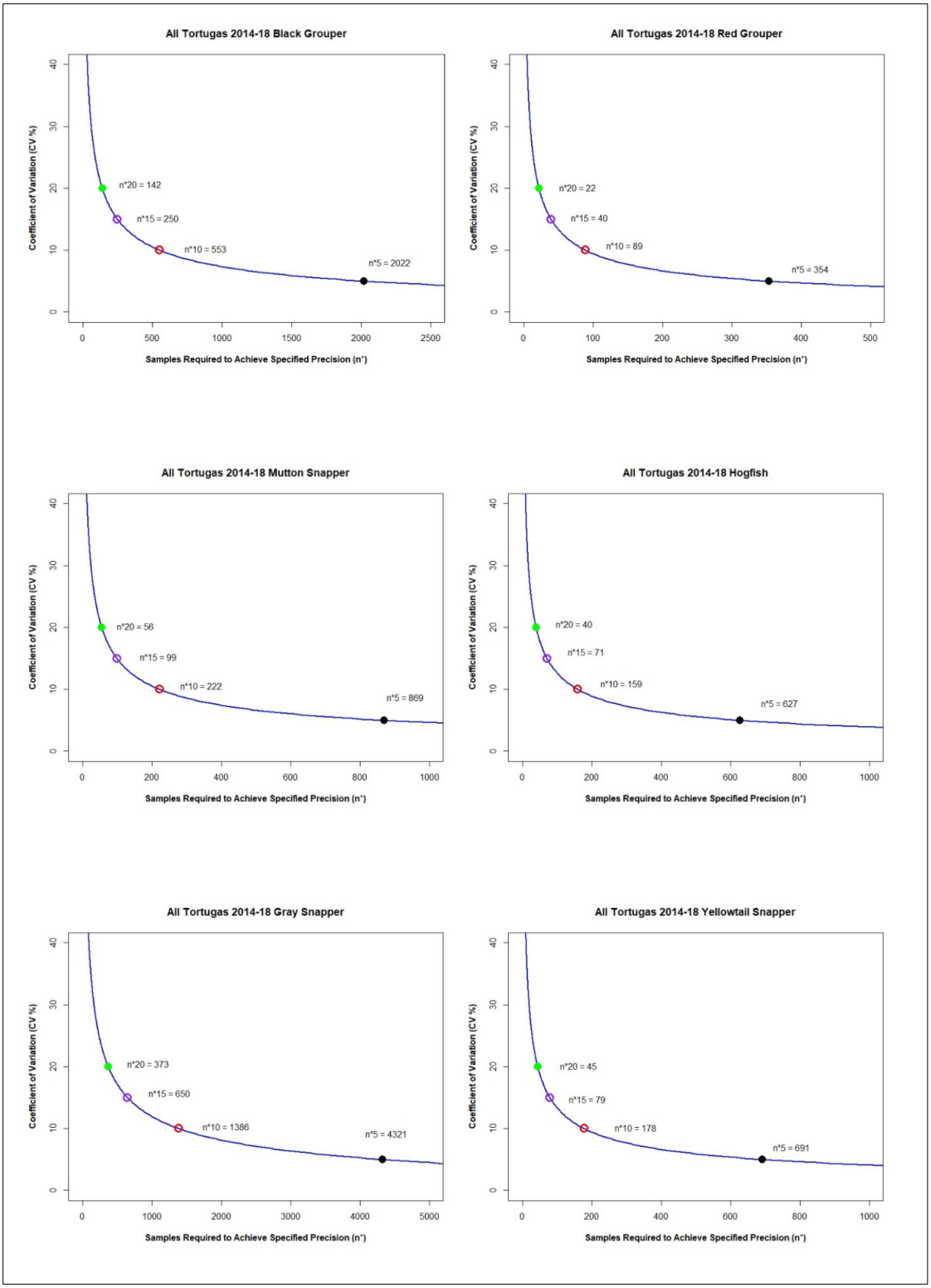


Figure 7. Performance (*n**) curves for 6 focal species in the Tortugas subregion. Based on one-stage stratified random surveys with expected CV values achieved by sampling effort based on 2014, 2016 and 2018 survey data. The sample sizes required to achieve a precision of 5, 10, 15, and 20% CV are also indicated.

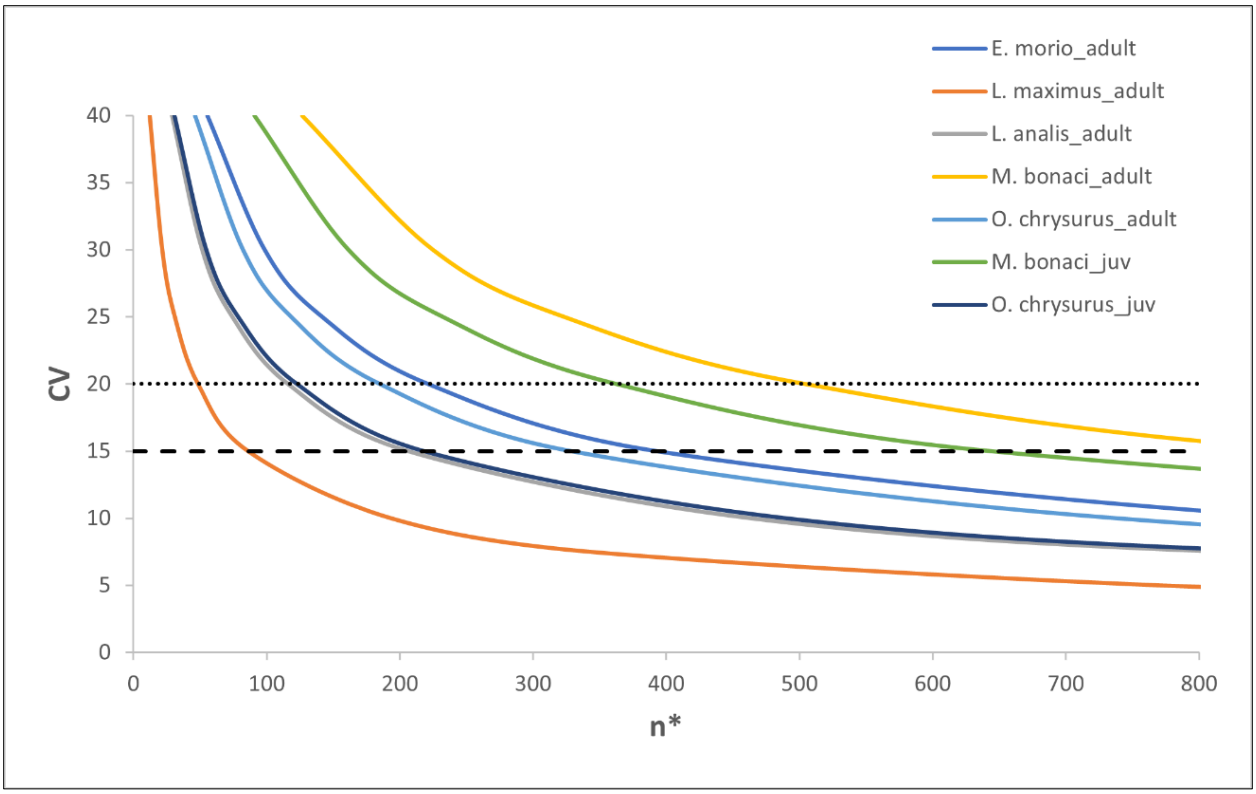


Figure 8. Performance (*n**) curves for select juveniles and/or adults of five focal species in the Florida Keys subregion: Red Grouper *(Epinephelus morio*), Hogfish *(Lachnolaimus maximus*), Mutton Snapper (*Lutjanus analis*), Black Grouper (*Mycteroperca bonaci*), and Yellowtail Snapper (*Ocyurus chrysurus*). Curves are based on one-stage stratified random surveys with expected CV values achieved by sampling effort based on 2014, 2016 and 2018 survey data. The dotted (20% CV) and dashed (15% CV) lines represent targeted CVs.

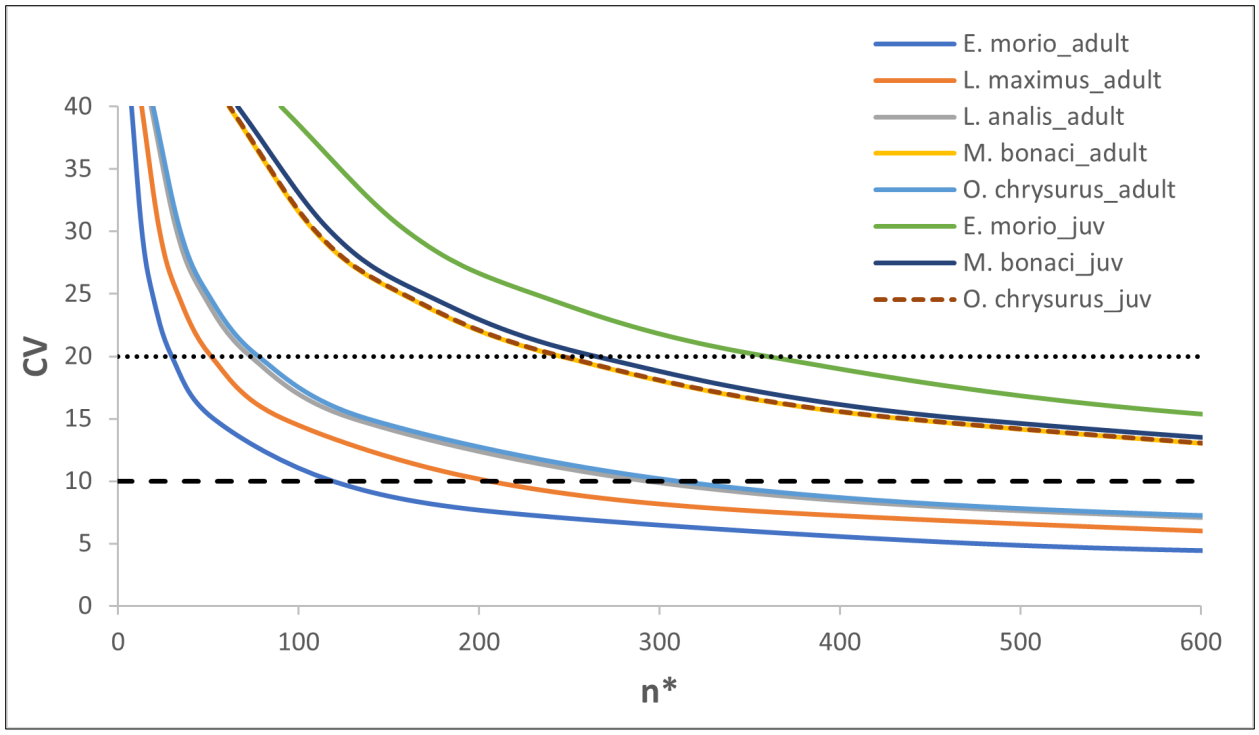


Figure 9. Performance (*n**) curves for select juveniles and/or adults of five focal species in the Tortugas subregion: Red Grouper (*Epinephelus morio*), Hogfish (*Lachnolaimus maximus*), Mutton Snapper (*Lutjanus analis*), Black Grouper *(Mycteroperca bonaci*), and Yellowtail Snapper (*Ocyurus chrysurus*). Curves are based on one-stage stratified random surveys with expected CV values achieved by sampling effort based on 2014, 2016 and 2018 survey data. The dotted (20% CV) and dashed (15% CV) lines represent target CVs.

United States Virgin Islands

Park managers and science partners composed a list of eight economically and ecologically important species that represent various trophic groups, territories and life history characteristics: Red Hind (*Epinephelus guttatus*), Coney (*Cephalopholis fulva*), Yellowtail Snapper (*Ocyurus chrysurus*), French Grunt (*Haemulon flavolineatum*), Foureye Butterflyfish (*Chaetodon capistratus*), Stoplight Parrotfish (*Sparisoma viride*), Blue Tang (*Acanthurus coeruleus*), and Queen Triggerfish (*Balistes vetula*). These species were used to help determine an appropriate stratification scheme and to optimally allocate sampling effort among strata. Previous work in the Florida Keys has shown that if commercially important species are used for survey optimization, precision levels for other species are often comparable (Brandt et al. 2009, Smith et al. 2011a). In the U.S. Virgin Islands, less traditional commercial or herbivorous species (e.g., parrotfishes and surgeonfishes) are also targeted by the fish trap fishery for consumption. However, the use of a select group of species does not connote that others will not benefit from the stratified sample design.

Estimates of performance analysis (*n**) regionwide and for each national park (BUIS, VIIS and VICR) were pooled across strata and calculated for eight focal species (Tables 9–11, Figures 9 and 10). Data to construct these figures came from sampling effort within each region from 2017 and 2019. CV values from previous surveys (2002–2015) were not available for comparison since these

years utilized a transect based visual count method (intercalibration study is not complete). The benefits of additional sampling required to reach a target level of precision within each region and management zone is illustrated in these tables and figures. Data are presented for all fish (juveniles and adults) by focal species but could also be presented by life stage. Note that there is no capture size limit for exploited reef fishes in the USVI territory except for Yellowtail Snapper ($L_{c\ \text{total length}}$ = 12 inches [30.5 centimeters {cm}]). In other words, all other fish life stages may be exploited.

Assuming a historical annual regional effort (n = 250), results with the one-stage stratified random sampling design and optimal allocation suggests that CV values are expected to be quite precise, with many focal species achieving a 10% CV in both the St. Croix and St. Thomas/St. John regions (Table 10, Figures 9–10), with the exception of Yellowtail Snapper in St.Croix. Yellowtail Snapper CVs across the St. Croix region are less precise, but the required sampling needed to significantly lower these values is not realistic (n = 714, CV = 20%). At the current level of effort a relatively reasonable CV of 40% is expected for Yellowtail Snapper. Further examination of the n^* graphs for each of the eight focal species shows additional sampling will lead to negligible gains in precision across the regions and parks. These results, based on average annual sample effort with the one-stage design and optimal allocation, suggest that CV values for most species used for optimization are expected to be between 15% and 20% for management zones in St. John (Table 11). However, increasing annual sampling effort to 60 annual surveys (from approximately 43) within the Virgin Islands Coral Reef NM is recommended to improve CVs for several key species. Buck Island Reef NM focal species' CVs are generally expected to range close to 15% to 20% with a survey effort of 100 sites, with the exception of Yellowtail Snapper (Table 12). It should be noted that sample sizes were too low for n^* curves to be effective for just Salt River Historic Park and Ecological Reserve alone. Since both Buck Island Reef NM and Salt River Historic Park and Ecological Reserve share comparable fishing regulations (No-Take Marine Reserves) and are located similarly on the north shore of St. Croix, it is recommended that surveys within these parks be pooled for allocation and analyses.

Table 10. Predicted survey effort needed to achieve coefficient of variation (CV) values for focal species in the USVI regions based on one-stage stratified random survey effort from 2017 and 2019. [A] Green shading indicates expected CVs based on the number of approximate historical targeted allocations (n = 250).

Common name	Code	STX - territory wide				STT/STJ - territory wide			
		n*20	n*15	n*10	n*5	n*20	n*15	n*10	n*5
Blue Tang	ACA COER	48[A]	86[A]	192[A]	762	43[A]	77[A]	173[A]	686
Coney	CEP FULV	16[A]	29[A]	65[A]	261	55[A]	98[A]	220[A]	872
Foureye Butterflyfish	CHA CAPI	65[A]	116[A]	261	1038	27[A]	48[A]	109[A]	433
French Grunt	HAE FLAV	209[A]	371	833	3281	203[A]	360	806	3111
Queen Triggerfish	BAL VETU	53[A]	94[A]	211[A]	841	94[A]	166[A]	373	1473
Red Hind	EPI GUTT	58[A]	104[A]	233[A]	928	50[A]	89[A]	199[A]	791
Stoplight Parrotfish	SPA VIRI	73[A]	129[A]	290	1152	46[A]	81[A]	182[A]	724
Yellowtail Snapper	OCY CHRY	714	1264	2817	10708	97[A]	172[A]	386	1522

Table 11. Predicted survey effort needed to achieve coefficient of variation (CV) values for focal species in Virgin Islands National Park (VIIS) and Virgin Islands and Coral Reef National Monument (VICR) in St. John, USVI based on one-stage stratified random survey effort from 2017 and 2019. [A] Green shading indicates expected CVs based on the number of approximate historical targeted allocations (VIIS n = 60; VICR n = 43).

Common name	Code	VIIS				VICR			
		n*20	n*15	n*10	n*5	n*20	n*15	n*10	n*5
Blue Tang	ACA COER	19[A]	33[A]	73	251	24[A]	42[A]	91	311
Coney	CEP FULV	96	168	360	1136	49	84	175	503
Foureye Butterflyfish	CHA CAPI	22[A]	39[A]	87	330	27[A]	48	104	354
French Grunt	HAE FLAV	100	166	310	653	53	86	154	294
Queen Triggerfish	BAL VETU	136	227	434	961	72	123	245	609
Red Hind	EPI GUTT	37[A]	65	144	518	60	104	215	601
Stoplight Parrotfish	SPA VIRI	29[A]	52[A]	114	406	37[A]	64	134	390
Yellowtail Snapper	OCY CHRY	50[A]	86	185	588	61	104	214	584

Table 12. Predicted survey effort needed to achieve coefficient of variation (CV) values for focal species in Buck Island Reef National Monument (BUIS) in St. Croix, USVI based on one-stage stratified random survey effort from 2017 and 2019. [A] Green shading indicates expected CVs based on approximate historical allocations (BUIS n = 100). **Note: Sample sizes too low for *n** curves to be effective for just SARI alone.**

Common name	Code	BUIS			
		n*20	n*15	n*10	n*5
Blue Tang	ACA COER	48[A]	84 [A]	181	592
Coney	CEP FULV	16 [A]	29 [A]	65 [A]	254
Foureye Butterflyfish	CHA CAPI	49 [A]	86 [A]	192	707
French Grunt	HAE FLAV	120	208	432	1220
Queen Triggerfish	BAL VETU	57 [A]	99 [A]	216	734
Red Hind	EPI GUTT	66 [A]	116	257	925
Stoplight Parrotfish	SPA VIRI	31 [A]	55 [A]	122	460
Yellowtail Snapper	OCY CHRY	325	551	1096	2697

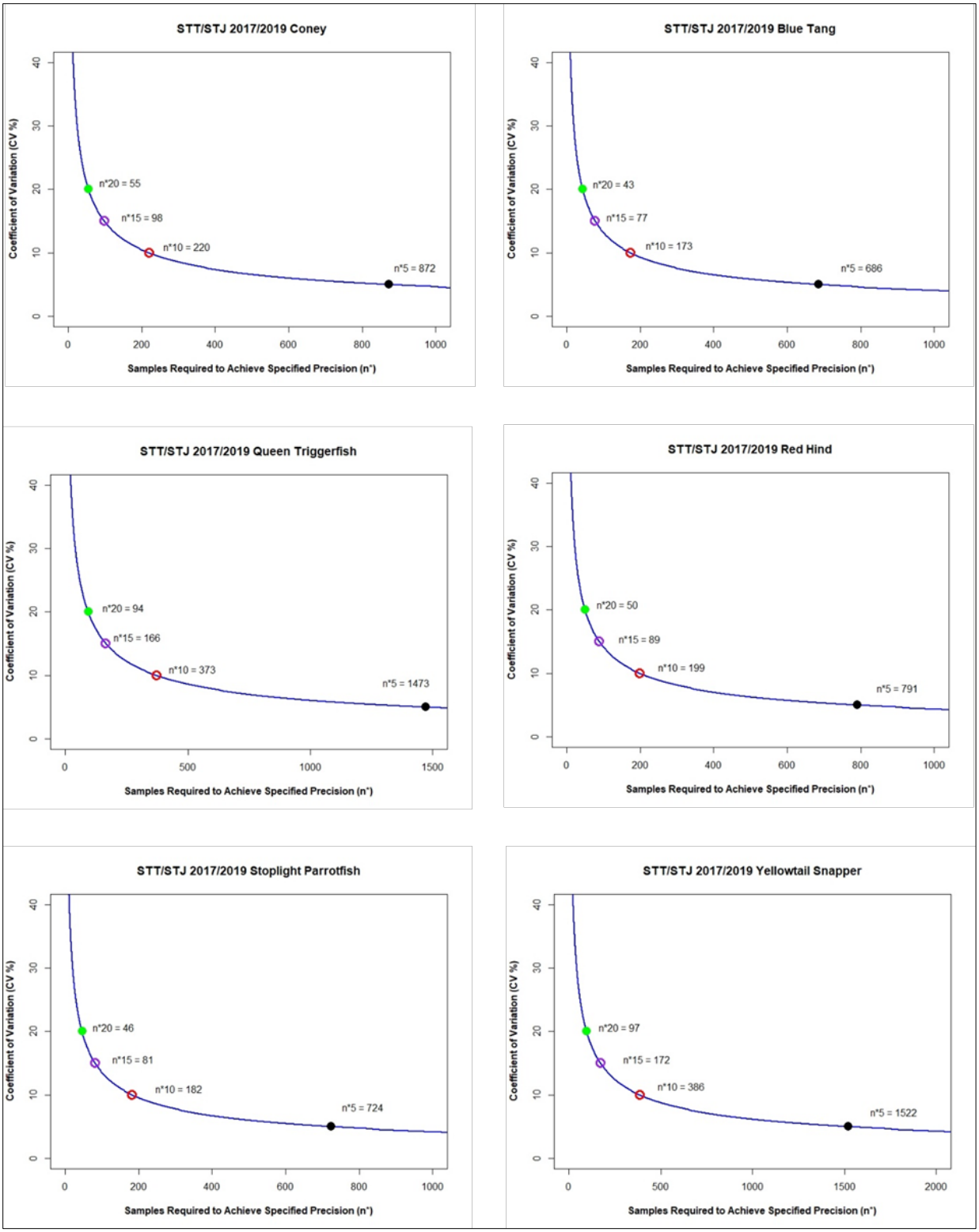


Figure 10. Performance (*n**) curves for 6 focal species in St. Thomas/St. John, USVI. Based on one-stage stratified random surveys with expected CV values achieved by sampling effort based on 2017 and 2019 survey data. The sample sizes required to achieve a precision of 5, 10, 15, and 20% CV are also indicated.

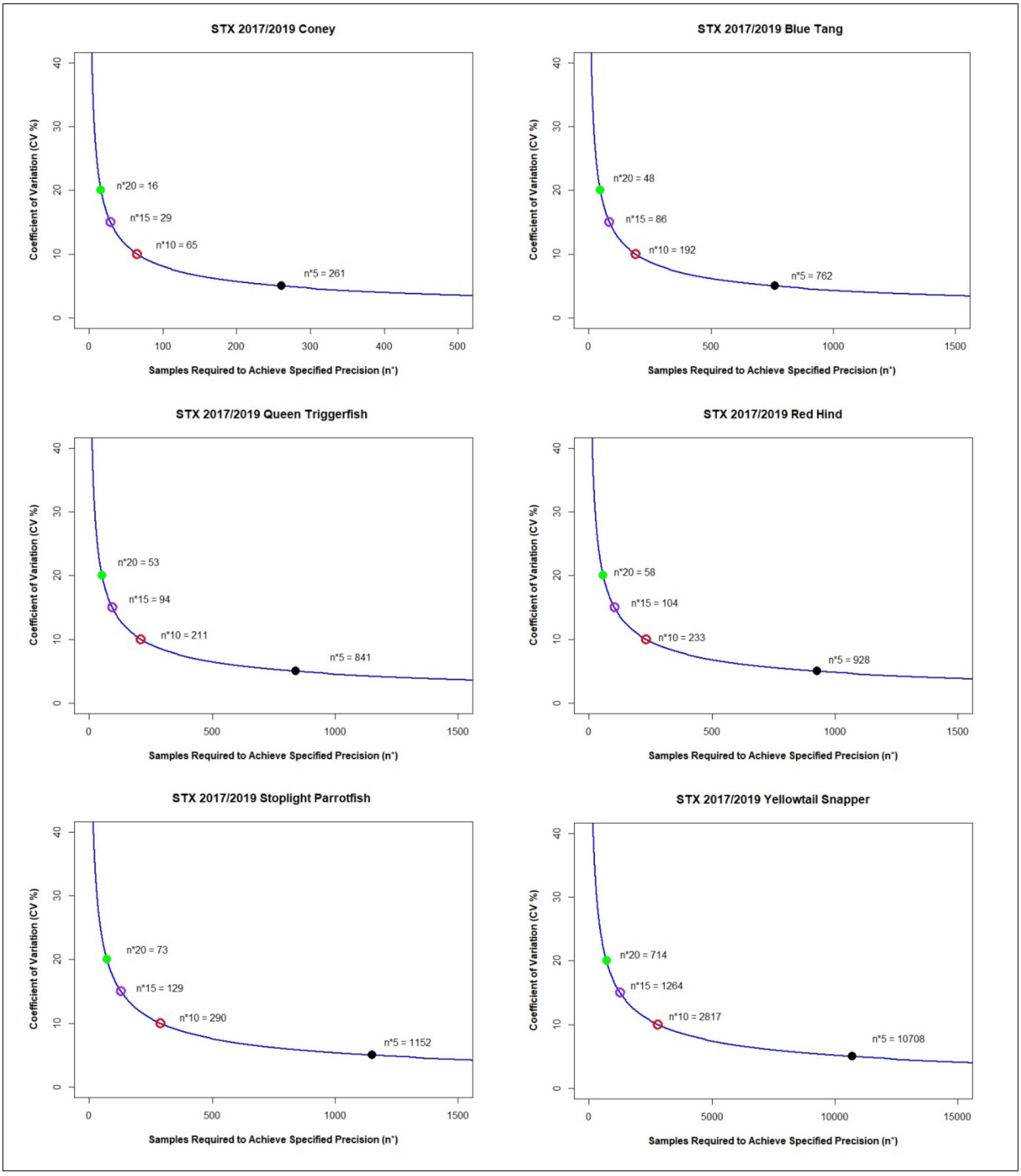


Figure 11. Performance (*n**) curves for six focal species in St. Croix, U.S Virgin Islands. Based on one-stage stratified random survey with expected CV values achieved by sampling effort based on 2017 and 2019 survey data. The sample sizes required to achieve a precision of 5, 10, 15, and 20% CV are also indicated.

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Appendix A. Benthic Habitat Maps, Habitat Classifications and Sample Frame Description in Florida

Unified Florida Reef Tract Map

The following is the metadata directly obtained from FWC's website where the Unified Florida Reef Tract Map is available for download (Version 2.0). The website serves as a comprehensive source for regional benthic habitats from West Palm Beach to the Dry Tortugas (FWC, 2020b). Multiple individual maps and classification systems were integrated and developed into a single product containing hierarchical Unified Classification levels that was made possible through a cooperative effort between FWC-FWRI and numerous partners. The map is updated as new data and areas become available. Further information, additional metadata and the GIS formatted version of the map can be found at: http://ocean.floridamarine.org/IntegratedReefMap/UnifiedReefTract.htm

Unified Reef Map v2.0 Metadata

Identification Information:

Citation:

Citation Information:

Title: Unified Reef Map v2.0

Geospatial Data Presentation Form: vector digital data

Publication Information:

Publisher: Florida Fish and Wildlife Conservation Commission-Fish and Wildlife Research Institute (FWRI FWC)

Online

Linkage: http://ocean.floridamarine.org/IntegratedReefMap/UnifiedReefTract.htm

Online Linkage: http://myfwc.com/research/gis/

Description:

Abstract: The Unified Reef Map is a regional map of benthic habitats that occur throughout the Florida reef tract. The Unified Reef Map consists of individual maps and monitoring data provided by our numerous partners. The purpose of the Unified Reef Map is to provide a comprehensive view of habitats from Martin County through the Florida Keys to the Dry Tortugas. The Unified Reef Map supports the larger effort to coordinate scientific research and promote a reef-wide approach for protecting Florida's reef tract. To create the URM, individual maps are integrated, data are edited where overlapping or neighboring maps disagree, and habitat classes are cross-walked to allow comparisons between maps. The URM symbolizes benthic habitats, or bottom types, using the

Unified Classification (UC) system. The UC framework allows translation between different classification schemes while retaining the original detailed information provided by our mapping partners. There are five hierarchical UC classes starting at UC Level 0 which represents broad habitat classes and can be consistently translated between individual maps. At the most detailed UC Level 4, benthic habitats are described differently between map providers and may differ throughout the Unified Reef Map. The UC system is also cross-walked to the Coastal and Marine Ecological Classification Standard (CMECS). Un-edited source maps provided by URM map partners are also available. The Unified Reef Map is a living map and will be updated as new data become available. Version 2.0 released January 2017. For more information visit: http://ocean.floridamarine.org/IntegratedReefMap/UnifiedReefTract.htm

Purpose: The purpose of the Unified Reef Map (URM) is to provide a seamless spatial representation of benthic habitats occurring in the Florida Reef Tract from Martin County through the Florida Keys to the Dry Tortugas. The primary goal of the URM project is to integrate individual maps throughout the Reef Tract using a GIS framework that allows translation between the various classification schemes while retaining original information provide the mapping source. The Unified Reef Map also supports the larger effort to coordinate scientific research and promote a reef-wide approach for protecting Florida's reef tract.

Supplemental Information: This project was made possible by the contribution of data and expertise from partners and funded by NOAA's Office of Ocean and Coastal Resource Management in partnership with the Florida Department of Environmental Protection's Coastal Management Program. See project metadata for individual source map credits.

Status:

Progress: In work

Maintenance and Update Frequency

: Continually

Spatial Domain:

Bounding Coordinates:

West Bounding Coordinate: -82.375

East Bounding Coordinate: -79.739

North Bounding Coordinate: 27.123

South Bounding Coordinate: 24.413

Point_of_Contact:

Contact_Information:

Contact_Organization_Primary:

Contact_Organization:

Florida Fish and Wildlife Conservation Commission-Fish and Wildlife Research Institute

Contact_Person: GISLibrarian@MyFWC.com

Contact_Address:

Address_Type: mailing and physical

Address:

Fish and Wildlife Research Institute 100 Eighth Avenue Southeast

City: St. Petersburg

State_or_Province: FL

Postal_Code: 33701

Contact_Voice_Telephone: 727-896-8626

Benthic Habitat Classifications in Florida

The parks in Florida (Biscayne NP and Dry Tortugas NP) use a different habitat classification scheme than the parks in the U.S. Virgin Islands (Buck Island Reef NM, Salt River Bay NHP&EP, and Virgin Islands NP). The following map class photo-interpretation key and photos are taken from Waara et al. (2011) and provide guidance on identifying hardbottom habitats in Biscayne NP and Dry Tortugas NP according to the map classes outlined in the System of Classification of Habitats in Estuarine and Marine Environments (SCHEME) for Florida (Madley et al. 2002). The Madley et al. (2002) report may be accessed here: http://myfwc.com/media/202216/gomp_report_5955.pdf.

Reef/Hardbottom

Hardened substrate of unspecified relief formed by the deposition of calcium carbonate by reef building corals and other organisms or exposed bedrock, possibly with various degrees of concealment from attached plant and animal colonization. Unconsolidated bottom and submerged aquatic vegetation may occur within these habitats, although in less abundance than the reef/hardbottom.

Coral Reef

Hardened substrate formed by reef building corals. Could be live coral or relict reefs. Often bedrock is the base for these reefs but the presence of coral or remnant coral on the surface is reason to categorize the dominant habitat as coral reef.

Platform Reef (also bank reef)

Hardened substrate formed by reef building corals that exist in a quasi-continuous structure along a shelf edge or similar drop-off removed from any coastline. These are typically elongate structures and may be referred to as bank reefs. The following Subclass categories may be present in various combinations within a platform reef.

Linear Reef

Linear, contiguous coral formations. Reef crest, fore reef, and back reef zones could be mapped as Linear Reef. Most often has associated spur and groove and reef rubble habitats.

Reef Terrace (high profile)

Contiguous reef with high complexity and high relief (> 2 meters [6.6 ft]; Figure 12).

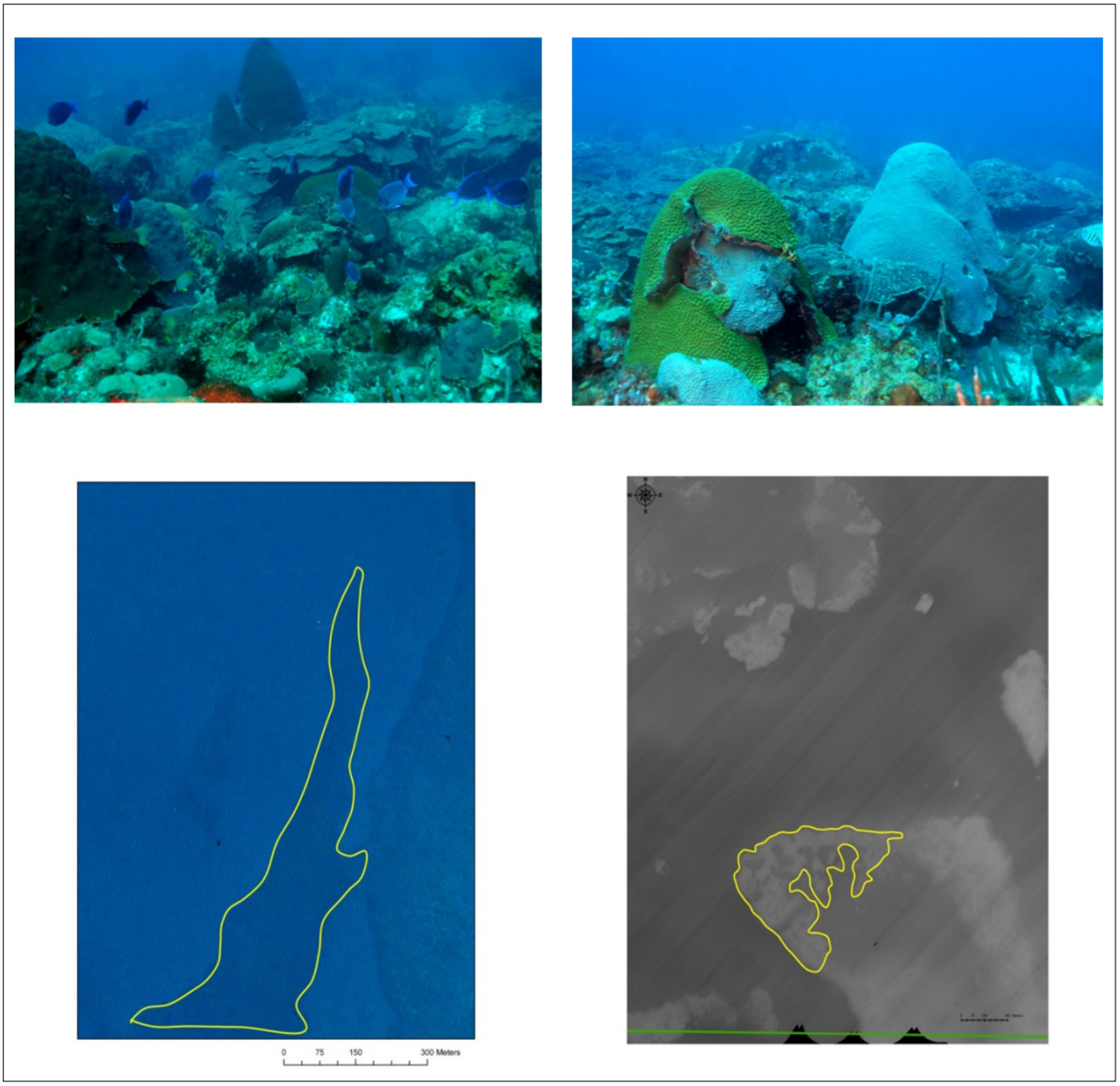


Figure 12. Photographic examples of linear reef terrace.

Remnant (low profile)

Reefs of relief less than 2 meters (6.6 ft) that lack distinctive spur and groove characteristics (Figure 13). These reefs consist of coral and hard bottom features; often support soft corals, sponges, seagrass; and are usually found growing parallel to the reef tract, though they may form transverse features that grow perpendicular to the reef tract.

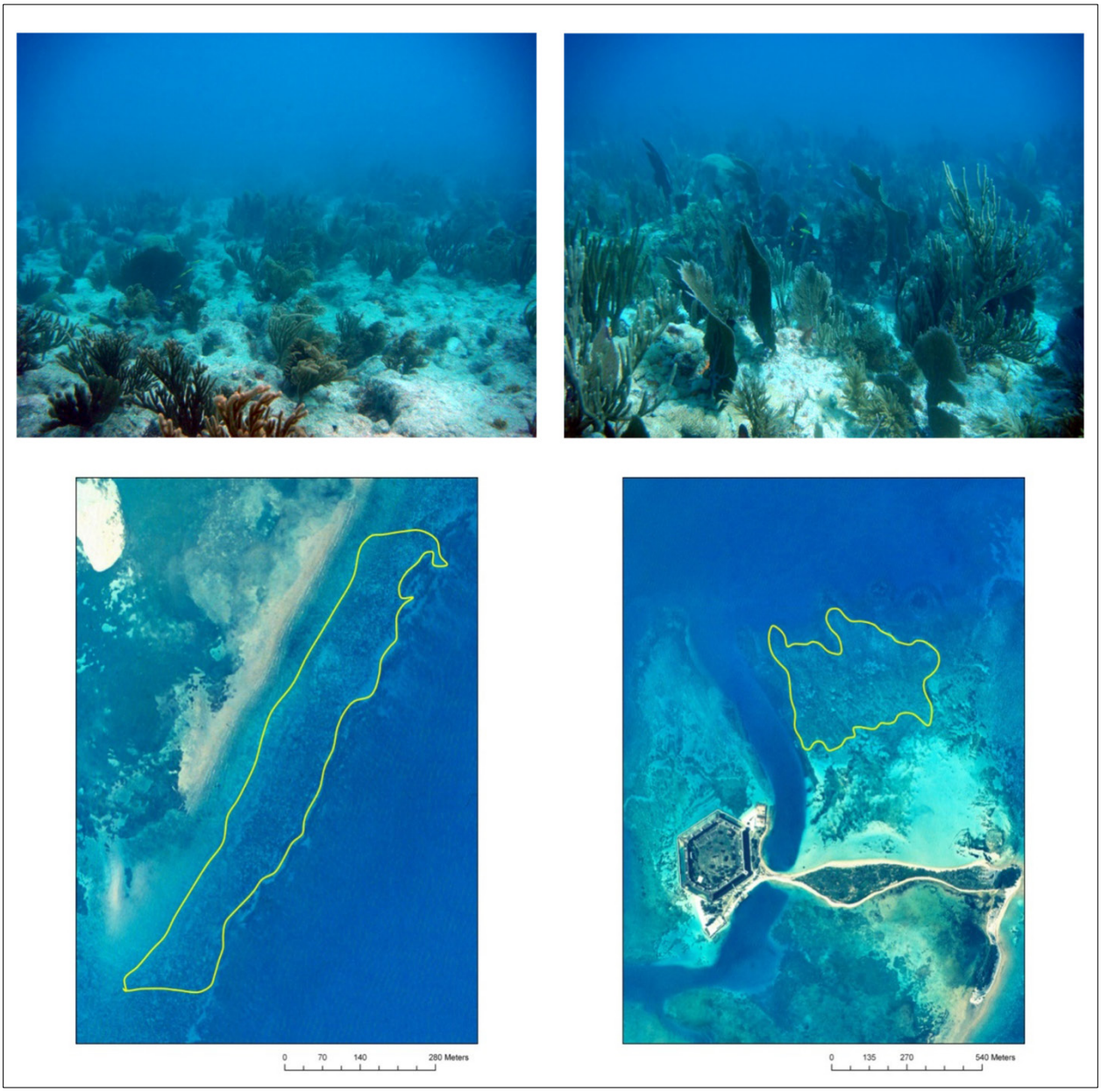


Figure 13. Photographic examples of linear reef remnant.

Spur and Groove

Distinct coral bands separated by sand or uncolonized hardbottom grooves. This habitat type usually occurs in the fore reef zone.

High Relief Spur and Groove

Distinct coral bands separated by sand or uncolonized hardbottom grooves (Figure 14). The coral bands have 1.5–4.0 meters (4.9–13.1 ft) relief.

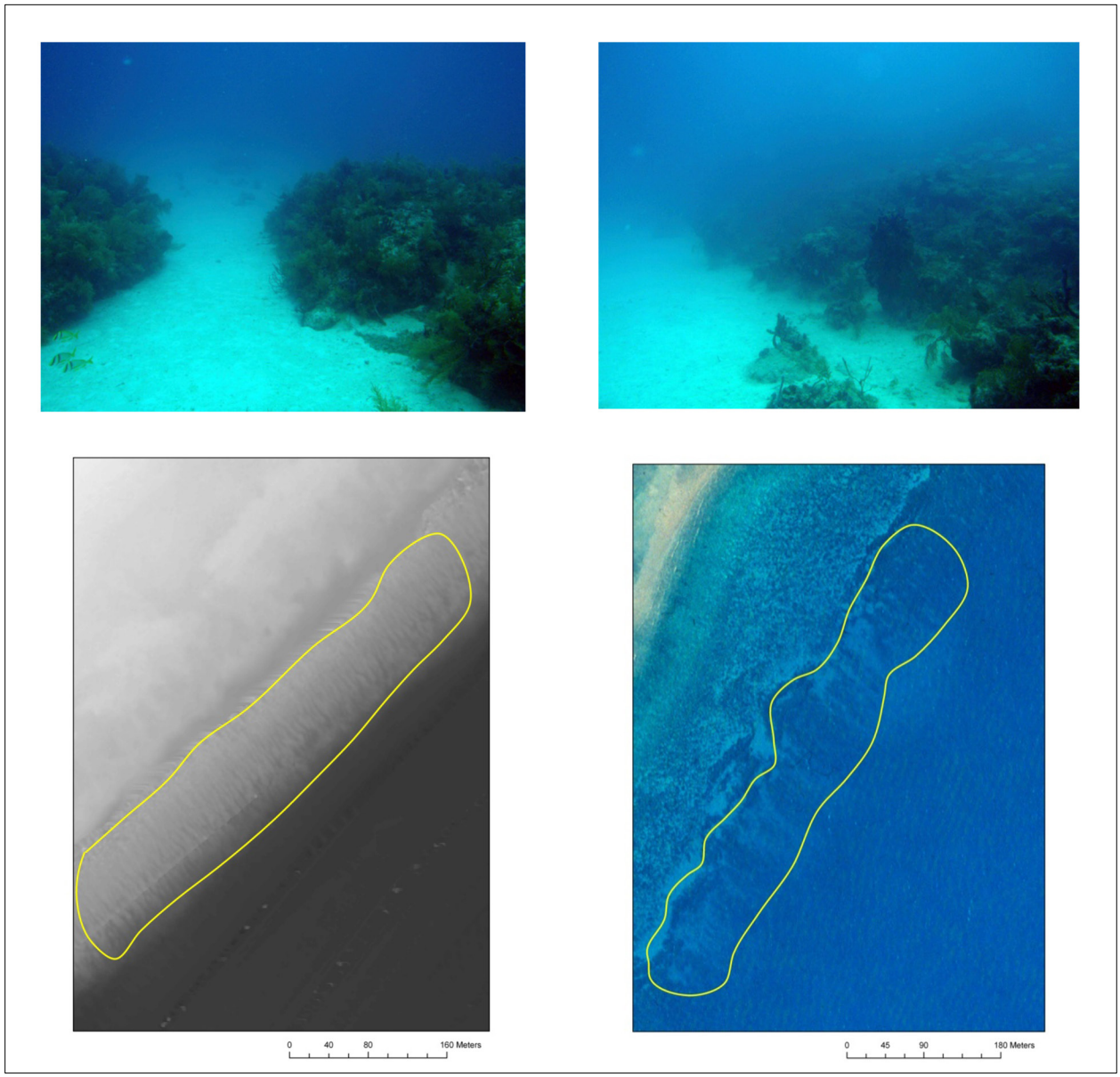


Figure 14. Photographic examples of high-relief spur and groove.

Low Relief Spur and Groove

Distinct coral bands oriented perpendicular to the shore or bank and separated by sand or uncolonized hardbottom grooves. The coral bands have less than 1.5 meters (4.9 ft) relief (Figure 15).

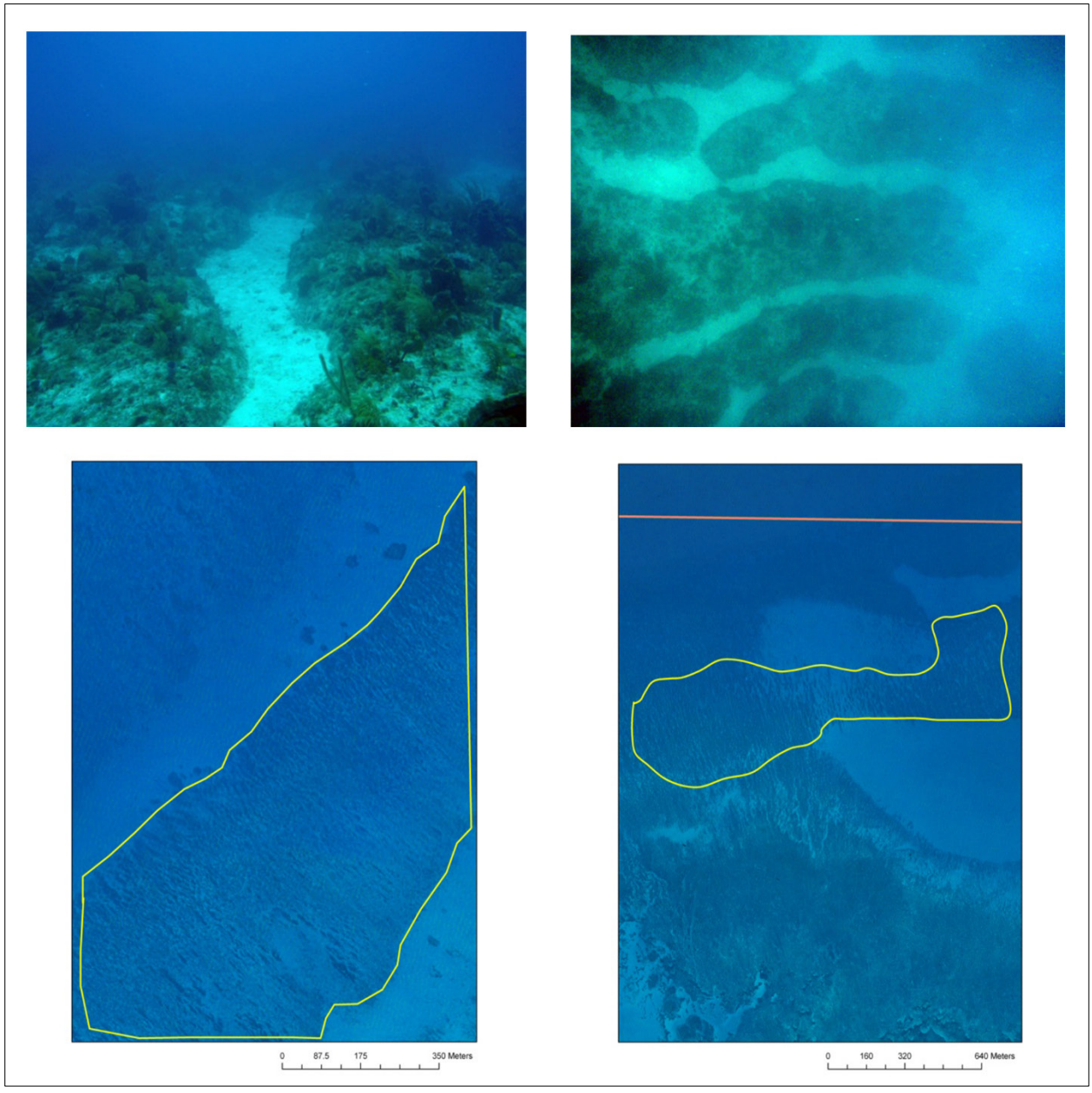


Figure 15. Photographic examples of low-relief spur and groove.

Reef Rubble

Dead, unstable coral rubble that often occurs landward of platform reefs.

Patch Reefs

Irregularly shaped reef communities. They may range in size from tens to thousands of square meters. Patches are separated from each other by uncolonized hardbottom, sand, or colonized substrate with submersed aquatic vegetation (SAV), macroalgae, gorgonians or sponges. Most often the patches are surrounded by a halo of bare substrate created by foraging, obligate reef inhabitants.

Individual Patch Reef

Isolated, single reef (larger than the 0.5 hectare [1.24 acre {ac}] minimum mapping unit of the project) without associated halo area (Figure 16). These individual reefs may have an associated halo, however if large enough (i.e., greater than the 0.5 hectare [1.24 ac] minimum mapping unit) to be delineated the halo will be mapped as its own subclass.

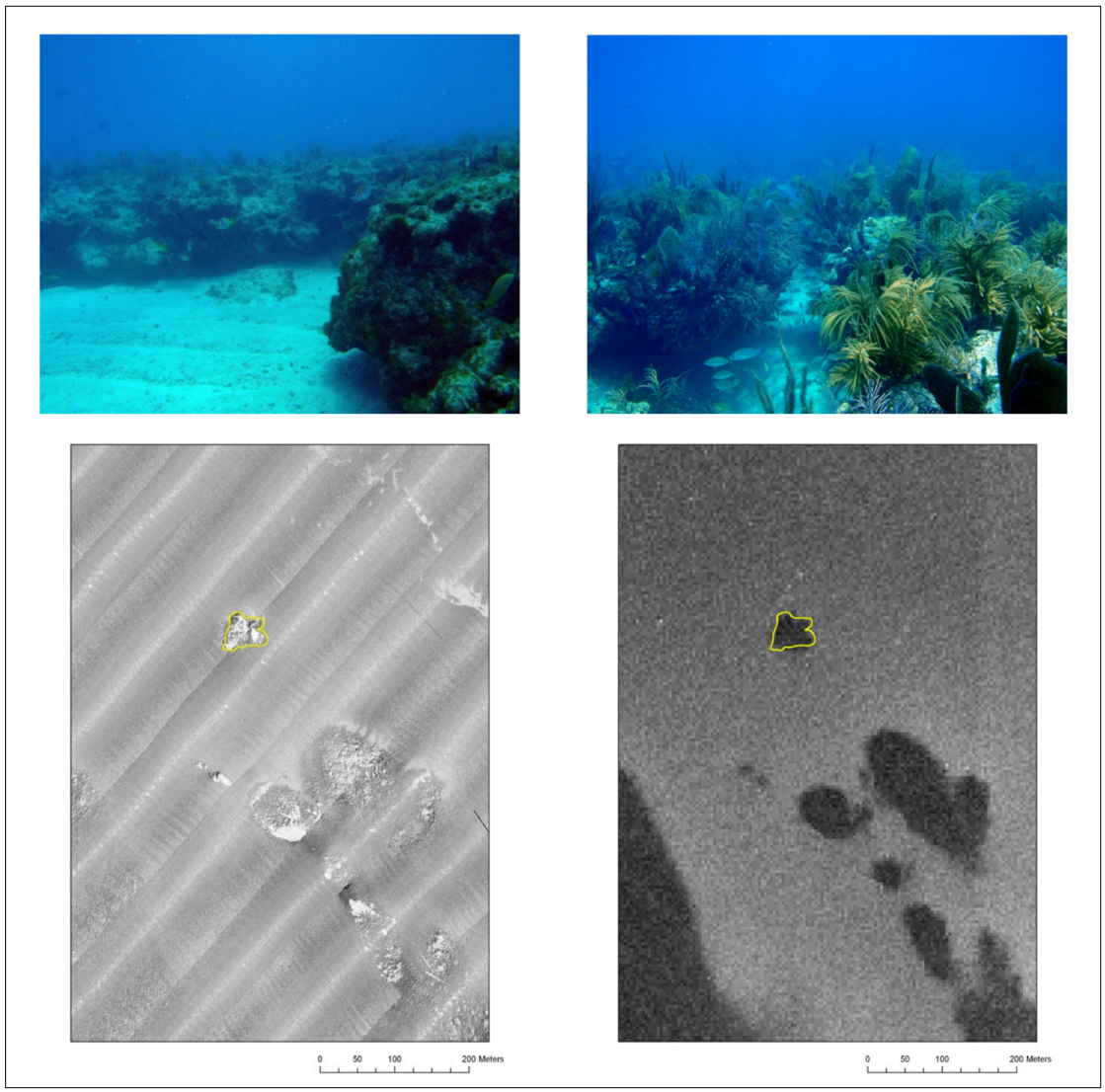


Figure 16. Photographic examples of individual patch reef.

Aggregated Patch Reefs (includes Halo areas if present)

High complexity patch reefs that have high relief (up to 15 meters [49.2 ft]) from the sea floor (Figure 17). These structures may occur in clusters and are typically surrounded by large sand plains.

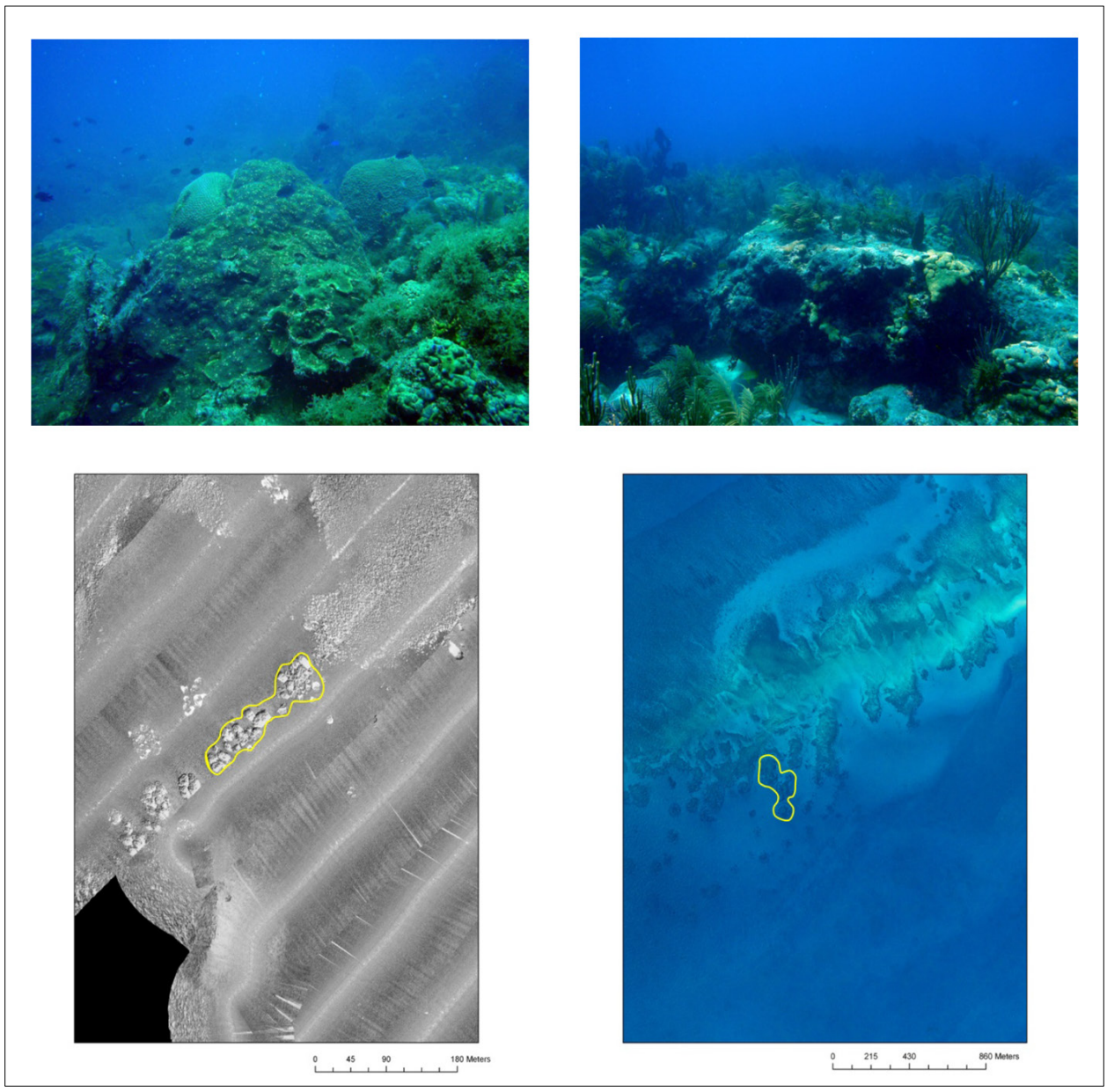


Figure 17. Photographic examples of aggregated patch reef.

Patchy Coral and/or Rock in Unconsolidated Bottom

Areas of primarily sand, submerged aquatic vegetation, or low relief rock covered with a sand veneer (Figure 18). Often adjacent to spur and groove habitats, these areas contain small, individual corals or rocks that are distinctive yet a very low percentage of the total cover (and certainly smaller than the 0.5 hectare [1.24 ac] minimum mapping unit).

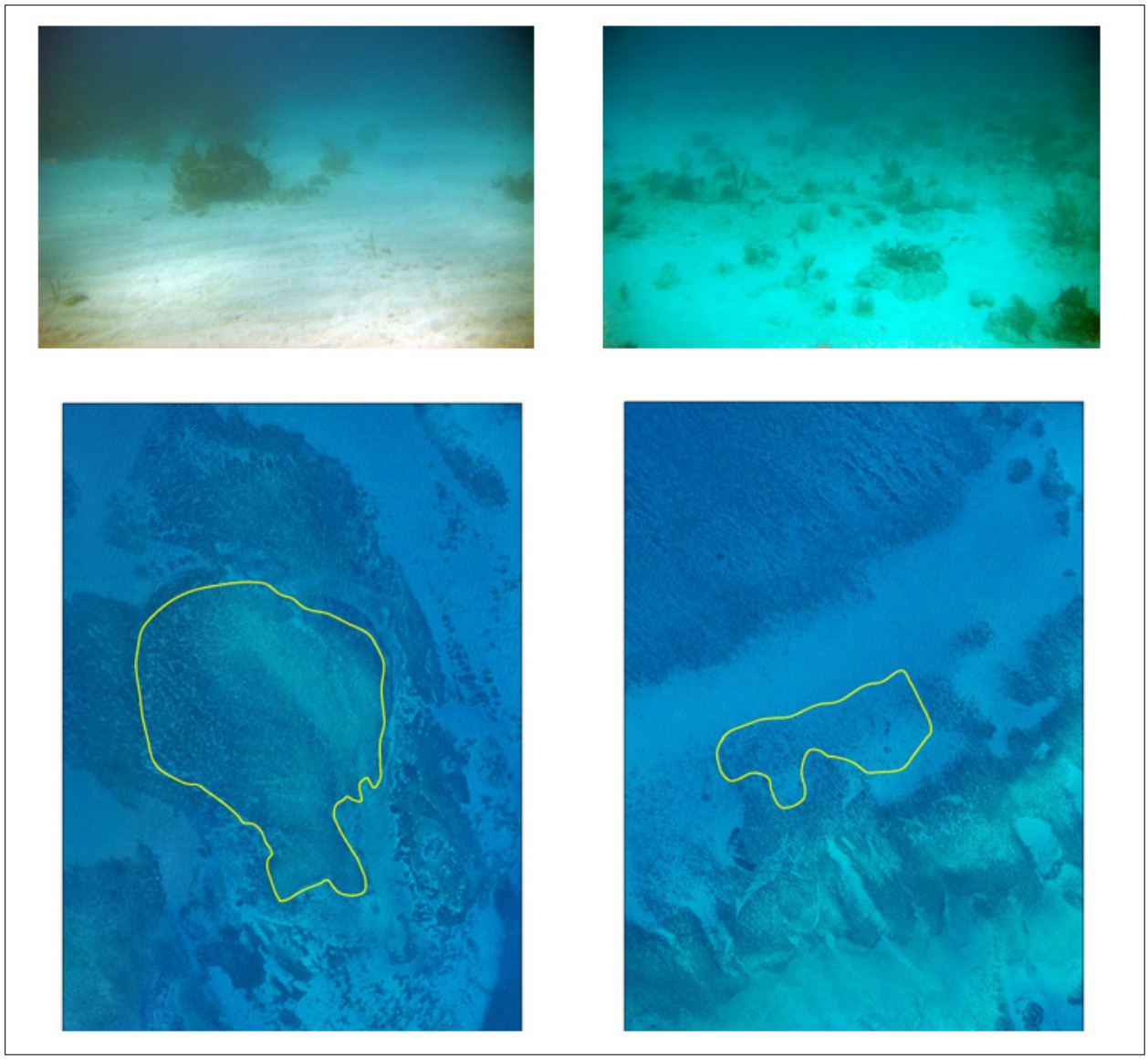


Figure 18. Photographic examples of patchy coral and/or rock in unconsolidated hardbottom.

Hardbottom

Hard substrate composed of exposed bedrock or created through syndepositional cementation of sediment.

Pavement (i.e., low relief hardbottom)

Flat, low relief, mostly solid rock substrate (Figure 19).

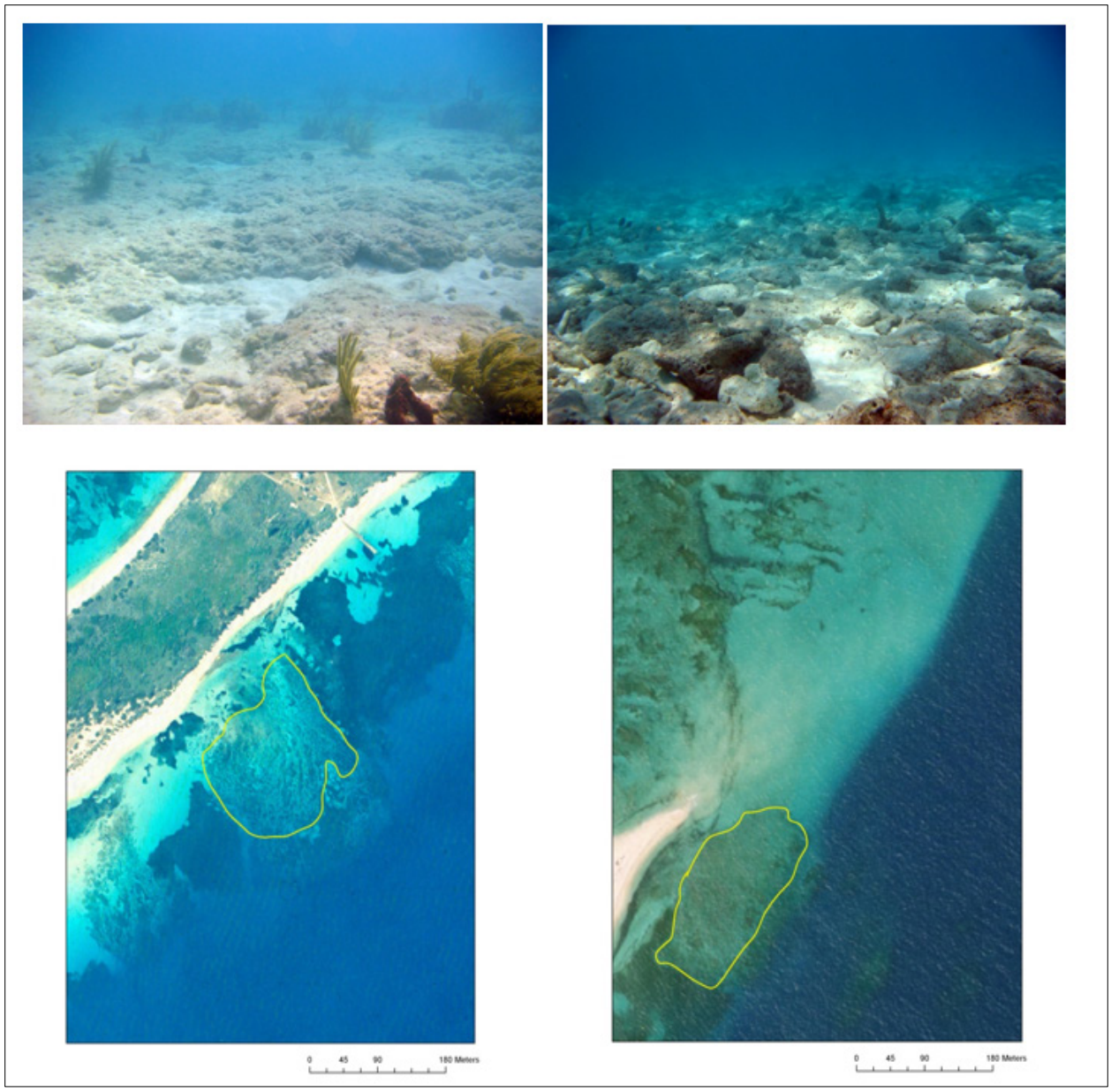


Figure 19. Photographic examples of pavement.

Florida Metadata

Included in this section are tables with descriptions of variables for habitats, zones and strata for the Florida region, including the Florida Keys and the Tortugas.

Table 13. Variables and Descriptions.

VARIABLE	DESCRIPTION
REGION	A code indicating the region in which a sample was taken.
MAPGRID_NR	A number indicating gridded shapefile number
LAT_DEGREE	Latitude in decimal degrees of grid cell centroid.
LON_DEGREE	Longitude in decimal degrees of grid cell centroid.
MAP_DEPTH	Average depth, in meters, of grid cell.
MAP_HAB_CD	A code indicating the habitat type.
SUBREG_NR	A number indicating the subregion.
ZONE_NR	A code indicating the onshore-offshore zonation
MPA_NR	A number identifying the marine protected area in which the sample was collected. Zero indicates unprotected status.
DEP_STRAT	A code indicating depth strata used in creating final stratification scheme
RUG_STRAT	A code indicating depth rugosity used in creating final stratification scheme
PROT	A boolean value indicating whether a sample was in a protected area (1), or not (0).
STRAT	A code indicating the stratum in which a sample was taken. Differs by region.

Table 14. Habitats and Habitat Types.

REGION	HABITAT_CD	HABITAT_TYPE
FLA KEYS	CONT_HR	Contiguous reef, non-spur-groove, high vertical relief
FLA KEYS	CONT_LR	Contiguous reef, non-spur-groove, low vertical relief
FLA KEYS	CONT_MR	Contiguous reef, non-spur-groove, moderate vertical relief
FLA KEYS	ISOL_HR	Isolated, patchy reef structures, high vertical relief
FLA KEYS	ISOL_LR	Isolated, patchy reef structures, low vertical relief
FLA KEYS	ISOL_MR	Isolated, patchy reef structures, moderate vertical relief
FLA KEYS	RUBB_LR	Reef rubble, low vertical relief
FLA KEYS	SPGR_HR	Spur-groove reef, high vertical relief
FLA KEYS	SPGR_LR	Spur-groove reef, low vertical relief
FLA KEYS	REEF_HR	High relief reef habitat

Table 15. Subregions.

SUBREGION_NR	SUBREGION_NAME
3	Tortugas-Tortugas Bank
4	Tortugas-Dry Tortugas NP
5	Tortugas-Unmapped
6	Marquesas-Tortugas Trans
7	Marquesas
8	Lower Keys
9	Middle Keys
10	Mid-Upper Keys Transition
11	Upper Keys
12	Biscayne
13	Broward-Miami
14	Deerfield
15	South Palm Beach
16	North Palm Beach
17	Martin

Table 16. Zones.

ZONE_NR	ZONE_NAME
0	Undetermined
1	Inshore
2	Mid Channel
3	Offshore Patch Reef
4	Forereef
5	Deepwater
6	Lagoon
7	Bank
9	Intra Island
10	Back Country Reef
20	New Grounds

Table 17. MPA List.

MPA_NR	MPA_NAME
0	Unprotected
1	Carysfort
2	Elbow
3	Key_Largo_Dry_Rocks
4	Grecian_Rocks
5	French
6	Molasses
7	Conch_Reef
8	Conch_RO
9	Davis
10	Hen_Chickens
11	Cheeca_Rocks
12	Alligator
13	Tennessee
14	Coffins_Patch
15	Sombrero
16	Looe_Key
17	Looe_RO
18	Newfound_Harbor
19	East_Sambo
20	West_Sambo
21	East_Dry_Rocks
22	Rock_Key
23	Sand_Key
24	Tortugas_NER
26	DTNP_RNA

Table 18. Descriptions of Depstrat.

DEPSTRAT	DESCRIPTION
D0	zone_nr=1, 2, 3; mostly depths <12m
D1	forereef (zone_nr=4), depth<12m
D2	forereef, 12m<=depth<22m
D3	forereef, 22m<=depth<33m

Table 19. Rugstrat Descriptions.

RUGSTRAT	DESCRIPTION
R1	substrate average vertical relief<0.15 m
R2	0.15m<=vertical relief<0.26m
R3	0.26m<=vertical relief<0.4m
R4	vertical relief>=0.4 m
RU	vertical relief unknown

Table 20. Zone, Depstrat and Rugstrat.

STRAT	ZONE_NR	DEPSTRAT	RUGSTRAT
S01	1	D0	
S02	2	D0	R1 & R2
S03	2	D0	R3 & R4
S04	2	D0	RU
S05	3 & 4	D1	R1 & R2
S06	3 & 4	D1	R3 & R4
S07	3 & 4	D1	RU
S08	3 & 4	D2	R1 & R2
S09	3 & 4	D2	R3 & R4
S10	3 & 4	D2	RU
S11	4	D3	–

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Waara, R. J., J. M. Patterson, A. J. Atkinson, and A. J. Estep. 2011. Development and policy applications of the 2010 benthic habitat map for Dry Tortugas National Park. Natural Resource Technical Report NPS/SFCN/NRTR—2011/474. National Park Service, Fort Collins, Colorado. Available at: DataStore - The 2010 Benthic Habitat Map For Dry Tortugas National Park (last accessed April 2025).

Appendix B. Benthic Habitat Maps, Habitat Classifications and Sample Frame Description in the United States Virgin Islands

USVI Benthic Habitat Maps

Below is the introductory metadata for the benthic habitat maps for St. Thomas and St. John, USVI and St. Croix, USVI. The NOAA National Centers for Coastal Ocean Science created benthic habitat maps of the shallow-water coral reef areas off Puerto Rico and the U.S. Virgin Islands in January 2000 through January 2002. These maps are updated as new remote sensing imagery and higher resolution data become available. Further information, additional metadata and the GIS formatted version of the map can be found at: https://coastalscience.noaa.gov/project/benthic-habitat-mapping-puerto-rico-virgin-islands/

St. Croix, USVI Metadata

Identification_Information:

Citation:

Citation_Information:

Originator: NOAA/NOS/NOAA/Biogeography Team

Publication_Date: 20010501

Title: Benthic Habitats of the U.S. Virgin Islands; St.Croix, USVI

Edition: 1

Geospatial_Data_Presentation_Form: vector digital data

Publication_Information:

Publication_Place: Charleston, SC

Publisher: NOAA Coastal Services Center

Description:

Abstract:

This project is a cooperative effort between NOAA's National Centers for Coastal Ocean Science (NCCOS), U.S. Geological Survey, National Park Service, and the National Geophysical Data Center, to produce benthic habitat maps and georeferenced imagery for the U.S. Virgin Islands. This project was was conducted in support of the U.S. Coral Reef Task Force.

Purpose:

This project was conducted in support of the U.S. Coral Reef Task Force.

Time_Period_of_Content:

Currentness_Reference: Ground condition at date photos were taken (1999)

Time_Period_Information:

Range_of_Dates/Times:

Beginning_Date: 1999

Ending_Date: 2001

Status:

Progress: complete

Maintenance_and_Update_Frequency: None planned

Spatial_Domain:

Bounding_Coordinates:

West_Bounding_Coordinate: -65.09

East_Bounding_Coordinate: -64.42

North_Bounding_Coordinate: 18.42

South_Bounding_Coordinate: 17.62

Point_of_Contact:

Contact_Information:

Contact_Person_Primary:

Contact_Person: Matthew S. Kendall

Contact_Organization: NOAA/NOS/NCCOS/Biogeography Program

Contact_Position: Marine Biologist

Contact_Address:

Address_Type: mailing and physical

Address: 1305 East West Highway, N/SCI-1

City: Silver Spring

State_or_Province: Maryland

Postal_Code: 20910

Country: USA

Contact_Voice_Telephone: 301-713-3028*144

Contact_Facsimile_Telephone: 301-713-4388

Contact_Electronic_Mail_Address: matt.kendall@noaa.gov

Hours_of_Service: 8:00 AM to 5:00 PM M-F EST

Data_Set_Credit:

USGS, NPS, VI. Dept. Planning Natural Resources; Div. Fish and Wildlife, Univ. VI, Cons. Data Center, The Nature Conservancy, Sea Grant, and other local and regional experts for input and review

Native_Data_Set_Environment: ArcView Shapefile

St. Thomas and St. John, USVI Metadata

Identification_Information:

Citation:

Citation_Information:

Originator: NOAA/NOS/NOAA/Biogeography Team

Publication_Date: 20010501

Title:

Benthic Habitats of the U.S. Virgin Islands; St.Thomas and St.John, USVI

Edition: 1

Geospatial_Data_Presentation_Form: vector digital data

Publication_Information:

Publication_Place: Charleston, SC

Publisher: NOAA Coastal Services Center

Description:

Abstract:

This project is a cooperative effort between NOAA's National Centers for Coastal Ocean Science (NCCOS), U.S. Geological Survey, National Park Service, and the National Geophysical Data Center, to produce benthic habitat maps and georeferenced imagery for the U.S. Virgin Islands. This project was was conducted in support of the U.S. Coral Reef Task Force.

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This project was conducted in support of the U.S. Coral Reef Task Force.

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Currentness_Reference: Ground condition at date photos were taken (1999)

Time_Period_Information:

Range_of_Dates/Times:

Beginning_Date: 1999

Ending_Date: 2001

Status:

Progress: complete

Maintenance_and_Update_Frequency: None planned

Spatial_Domain:

Bounding_Coordinates:

West_Bounding_Coordinate: -65.09

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North_Bounding_Coordinate: 18.42

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Contact_Person: Matthew S. Kendall

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Country: USA

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Contact_Facsimile_Telephone: 301-713-4388

Contact_Electronic_Mail_Address: matt.kendall@noaa.gov

Hours_of_Service: 8:00 AM to 5:00 PM M-F EST

Data_Set_Credit:

USGS, NPS, VI. Dept. Planning Natural Resources; Div. Fish and Wildlife, Univ. VI, Cons. Data Center, The Nature Conservancy, Sea Grant, and other local and regional experts for input and review

Native_Data_Set_Environment: ArcView Shapefile

Habitat Classifications in the United States Virgin Islands

The parks in the U.S. Virgin Islands (Buck Island Reef National Monument, Salt River Bay National Historical Park and Ecological Preserve, and Virgin Islands National Park) use a different habitat classification scheme than the parks in Florida parks (Biscayne National Park and Dry Tortugas National Park). A detailed description of the five hardbottom habitats (linear reef, patch reef, bedrock, pavement, and scattered coral/rock) used for this protocol can be found in Kendall et al. (2001). An excerpt from that document is included below in this appendix.

Linear reef: A combination of linear reefs and spur and groove formations.

Linear reef: Linear coral formations that are oriented parallel to shore or the shelf edge (Figure 20 and Figure 21). These features follow the contours of the shore/shelf edge. This category is used for such commonly-used terms as fore reef, fringing reef, and shelf edge reef.

Spur and groove: Habitat having alternating sand and coral formations that are oriented perpendicular to the shore or bank/shelf escarpment (Figure 20 and Figure 22). The coral formations (spurs) of this

feature typically have a high vertical relief compared to pavement with sand channels and are separated from each other by 1–5 meters (3.2–16.4 ft) of sand or bare hardbottom (grooves), although the height and width of these elements may vary considerably. This habitat type typically occurs in the fore reef or bank/shelf escarpment zone.

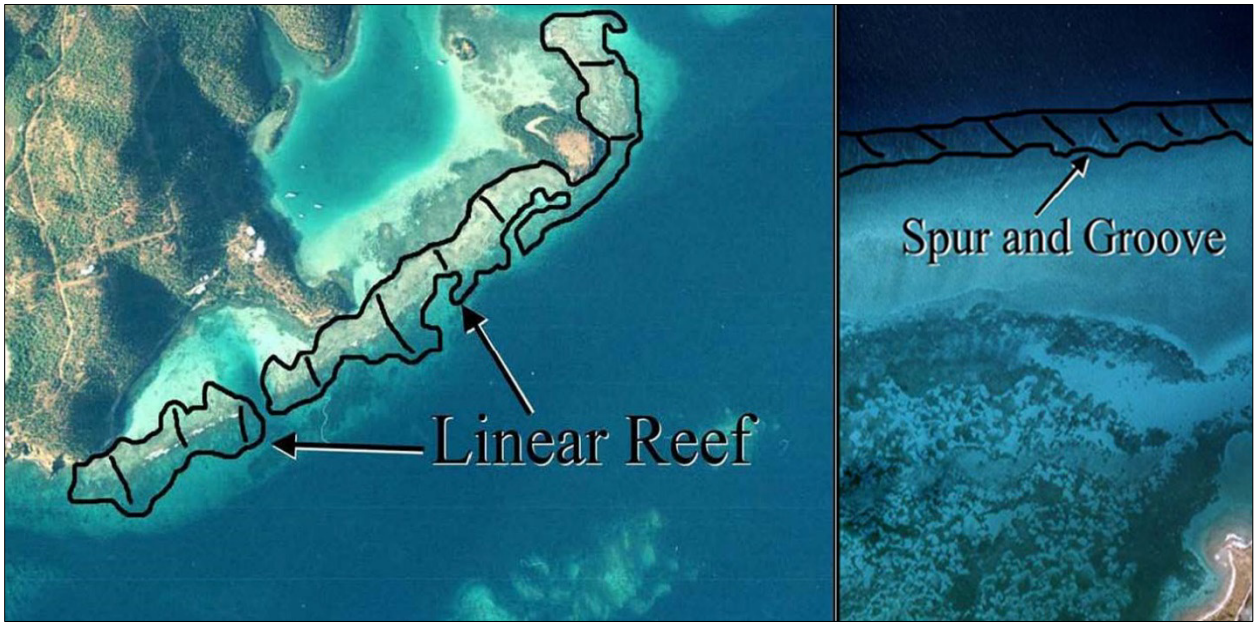


Figure 20. Examples of linear reef and spur and groove.

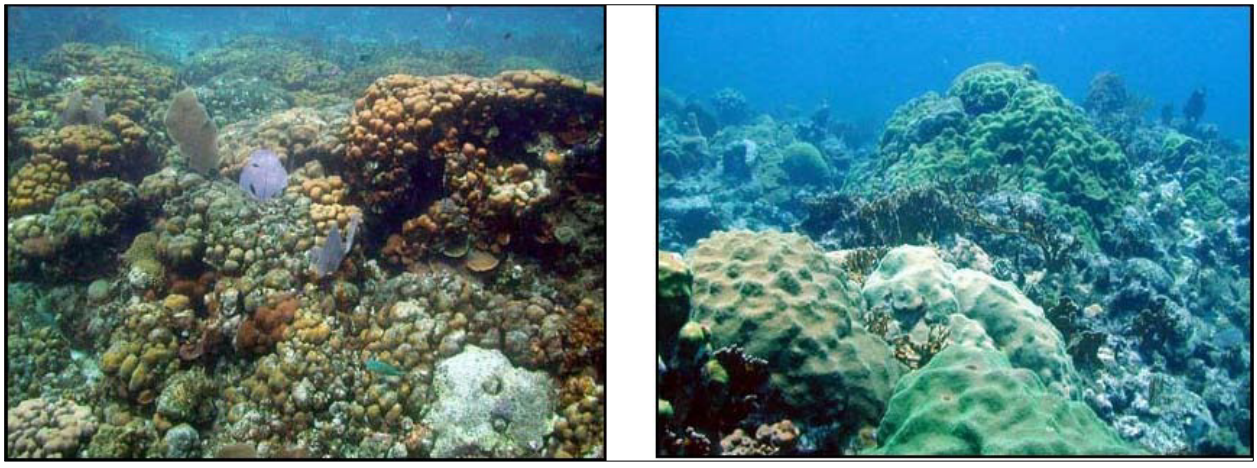


Figure 21. Examples of linear reef.

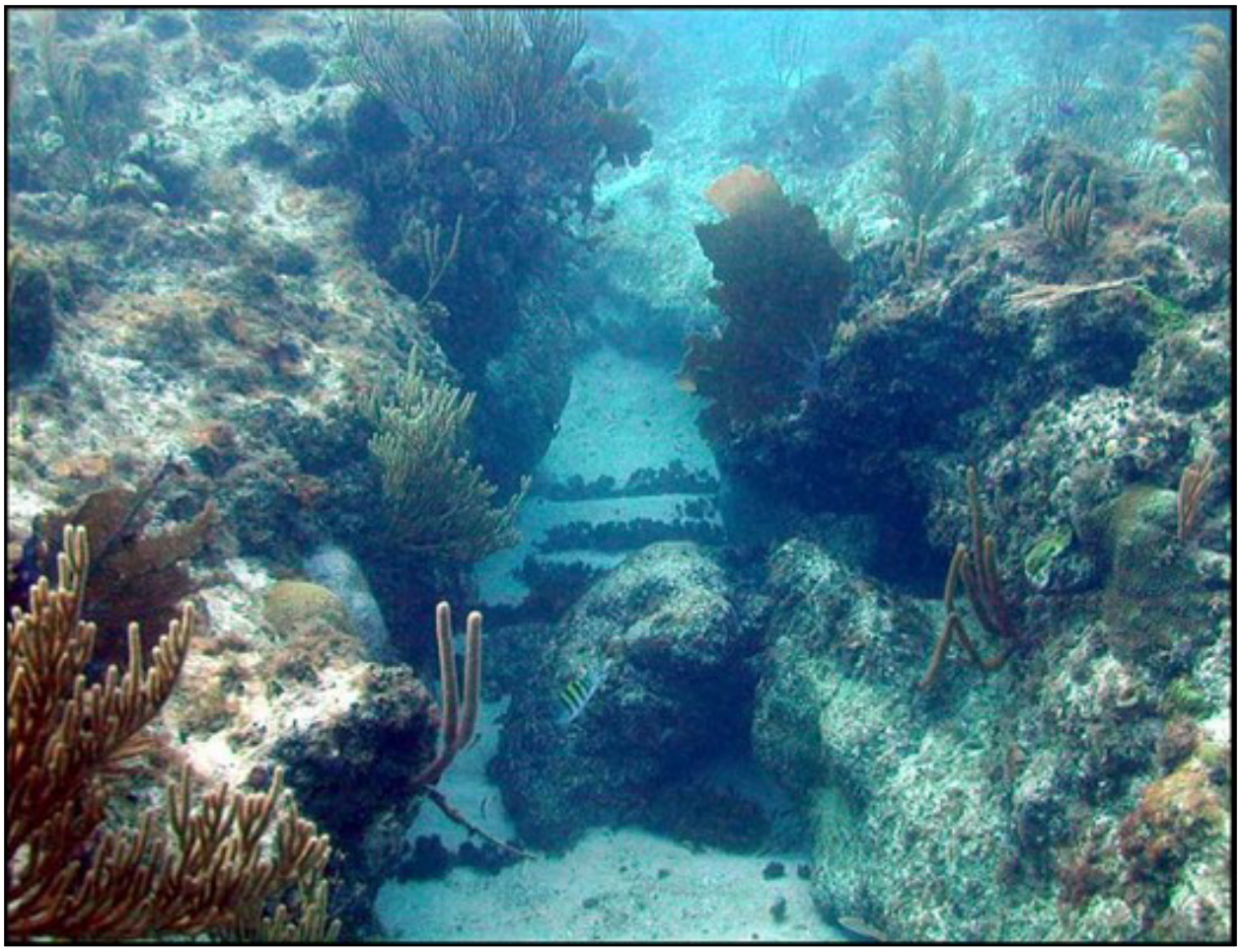


Figure 22. Example of spur and groove.

Patch reef(s): Coral formations that are isolated from other coral reef formations by sand, seagrass, or other habitats and that have no organized structural axis relative to the contours of the shore or shelf edge. A surrounding halo of sand is often a distinguishing feature of this habitat type when it occurs adjacent to submerged vegetation. Two types of patch reefs were combined.

Individual patch reef: Distinctive single patch reefs that are equal to or larger than the 0.4 hectare (1 acre) minimum mapping unit (Figure 23). When patch reefs occur in submerged vegetation and a halo is present, the halo is included with the patch reef polygon.

Aggregate patch reefs: Clustered patch reefs that individually are too small (smaller than the 0.4 hectare [1 acre] minimum mapping unit) or are too close together to map separately (Figure 23). Where aggregate patch reefs share halos, the halo is included in the polygon.

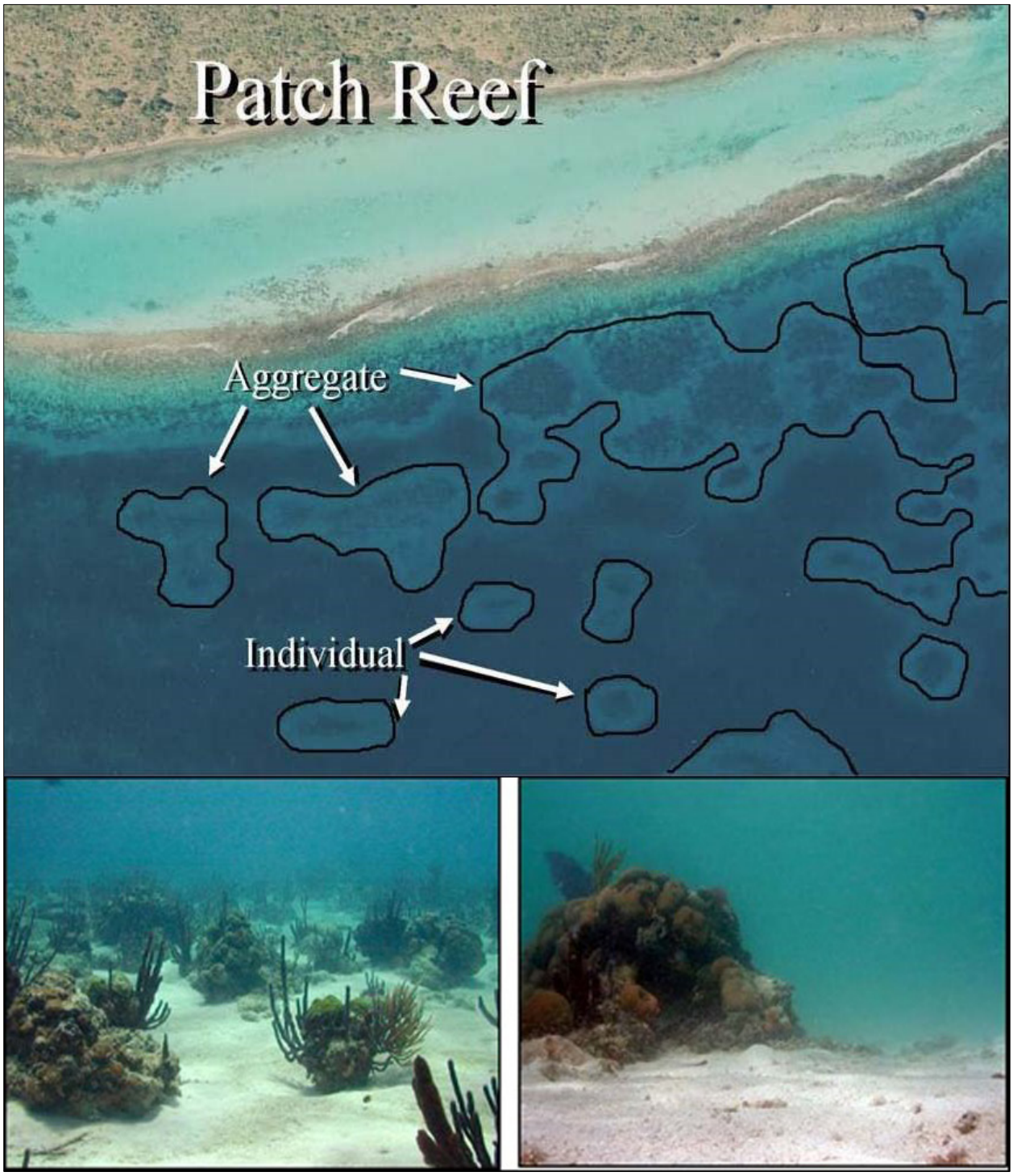


Figure 23. Example of patch reefs.

Bedrock: The geological formation and subsequent erosion has resulted in the exposure of bedrock in the Virgin Islands. Colonized and uncolonized bedrock were combined into a single bedrock category.

Colonized bedrock: Exposed bedrock contiguous with the shoreline that has coverage of macroalgae, hard coral, gorgonians, and other sessile invertebrates that partially obscures the underlying rock (Figure 24).

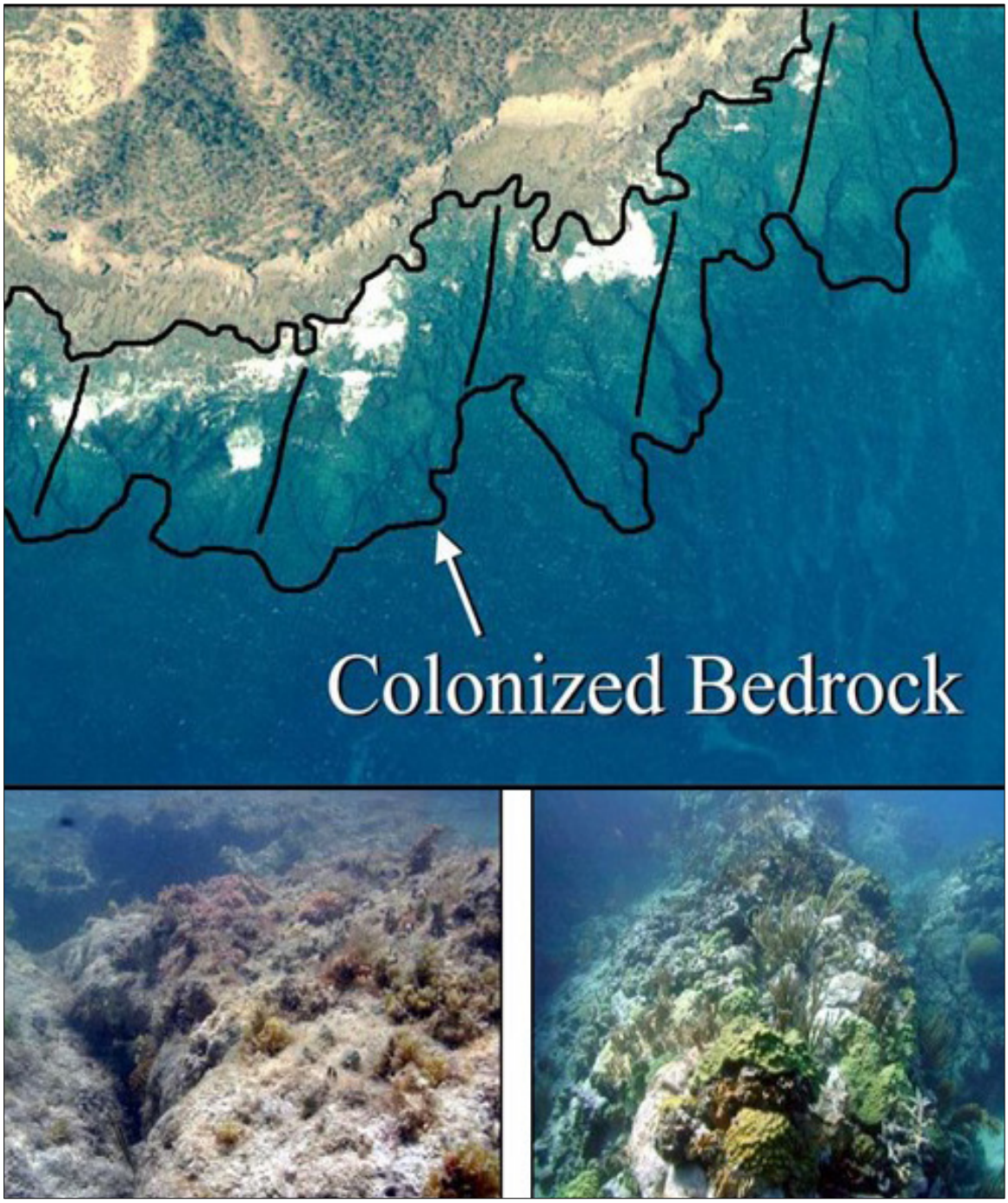


Figure 24. Example of colonized bedrock.

Uncolonized Bedrock: Exposed bedrock contiguous with the shoreline that has sparse coverage of macroalgae, hard coral, gorgonians and other sessile invertebrates that does not obscure the underlying rock (Figure 25 and Figure 26).

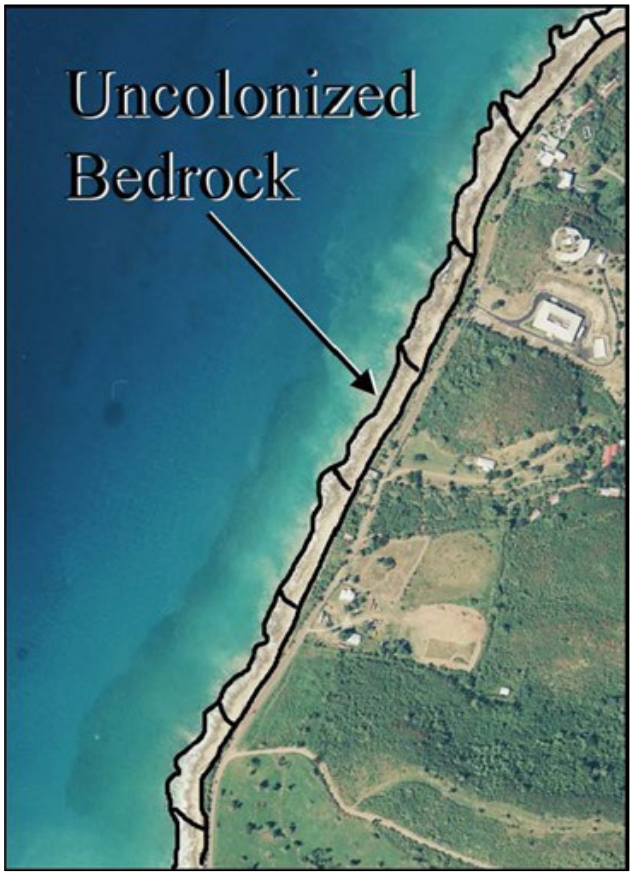


Figure 25. Example of aerial view of uncolonized bedrock.

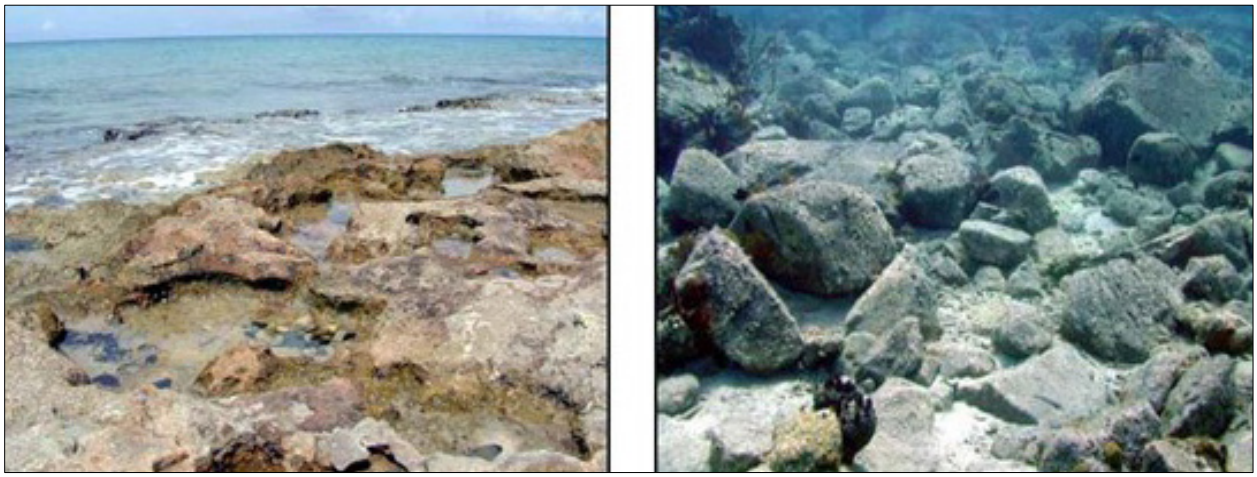


Figure 26. Example of uncolonized bedrock.

Pavement: Solid carbonate rock that constitutes the majority of hardbottom habitat on the Virgin Islands' shelf was classified as a general pavement category. The pavement category is a combination of: colonized pavement, colonized pavement with sand channels, uncolonized pavement and uncolonized pavement with sand channels.

Colonized pavement: Flat, low-relief, solid carbonate rock with coverage of macroalgae, hard coral, gorgonians, and other sessile invertebrates that are dense enough to partially obscure the underlying carbonate rock (Figure 27).



Figure 27. Example of colonized pavement.

Colonized Pavement with Sand Channels: Habitat having alternating sand and colonized pavement formations that are oriented perpendicular to the shore or bank/shelf escarpment (Figure 28). The sand channels of this feature have low vertical relief compared to spur and groove formations. This habitat type occurs in areas exposed to moderate wave surge such as that found in the bank/shelf zone.



Figure 28. Example of aerial view of colonized pavement with sand channels.

Uncolonized pavement: Flat, low relief, solid carbonate rock that is often covered by a thin sand veneer (Figure 29). The pavement's surface often has sparse coverage of macroalgae, hard coral, gorgonians, and other sessile invertebrates that does not obscure the underlying carbonate rock.



Figure 29. Example of uncolonized pavement.

Uncolonized pavement with sand channels: Habitat having alternating sand and uncolonized pavement formations that are oriented perpendicular to the shore or bank/shelf escarpment (Figure

30). The sand channels of this feature have low vertical relief compared to spur and groove formations.



Figure 30. Example of uncolonized pavement with sand channels.

Scattered coral/rock: This category is a combination of scattered coral/rock in unconsolidated sediment and reef rubble.

Scattered coral/rock in unconsolidated sediment: Primarily sand or seagrass bottom with scattered rocks or small, isolated coral heads that are too small to be delineated individually (i.e., smaller than individual patch reef) (Figure 31).

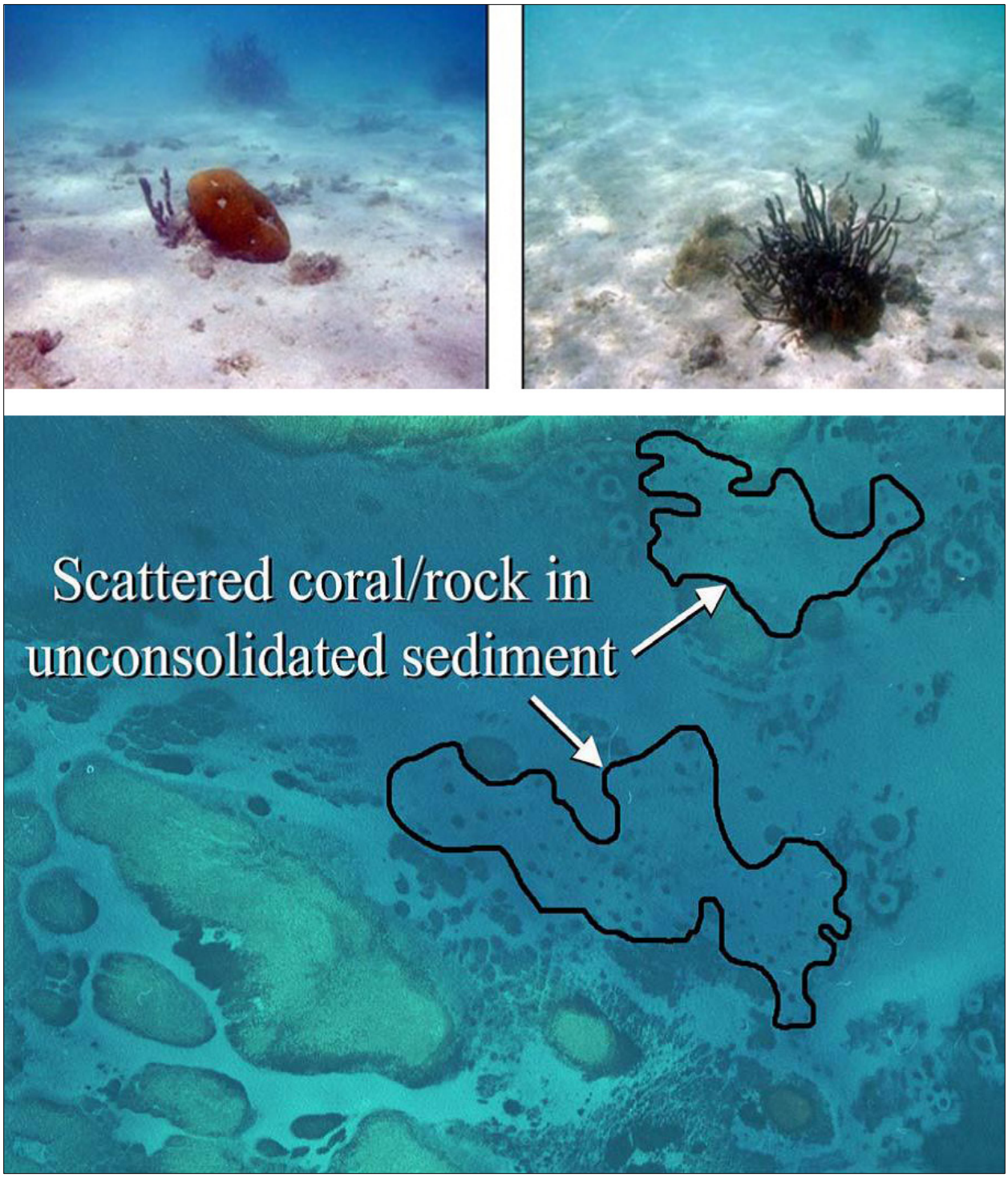


Figure 31. Example of scattered coral/rock in unconsolidated sediment.

USVI Metadata

Included in this section are tables with descriptions of variables for habitats, zones and strata for the United States Virgin Islands including the St. Thomas/St. John region and the St. Croix region.

Table 21. Descriptions of Variables.

VARIABLE	DESCRIPTION
GRID_ID	A number indicating gridded shapefile number
REGION	A code indicating the region in which a sample was taken.
LAT	Latitude of grid cell centroid
LONG	Longitude of grid cell centroid
Depth_MIN	Minimum depth (meters) of grid cell
Depth_MAX	Maximum depth (meters) of grid cell
Depth_MEAN	Mean depth (meters) of grid cell
DEPTH_M	Depth (meters) of grid cell centroid
PERC_AREA	Percentage of hardbottom area in grid cell
DEPTH	Depth stratum
HABITAT	A code indicating the habitat type.
SUB_REGION	Code indicating a geographical area in Region
ADMIN	Code indicating a named managed area
HZRD_FLAG	Boolean code indicating diving hazard. Cell is retained for analysis but removed for diving.
HB_FLAG	Boolean code indicating diving hazard. Cell is retained for analysis but removed for diving.
SHOR_FLAG	Boolean code indicating shore diving hazard. Cell is retained for analysis but removed for diving.
STRATUM	A code indicating the stratum in which a sample was taken. Differs by region.

Table 22. Habitats.

REGION	HABITAT_CD	HABITAT_TYPE
STX, STTSJ	AGRF	Aggregate reef
STX, STTSJ	BDRK	Bedrock
STX, STTSJ	HARD	Hard (unknown)
STX, STTSJ	PTRF	Patch reef (Aggregate and individual)
STX, STTSJ	PVMT	Pavement
STX, STTSJ	SCR	Scattered coral and rock

Table 23. Subregions.

REGION	SUBREGION_NR	SUBREGION_NAME
STX	ESTX	Eastern St. Croix
STX	LANG	Lang Bank
STX	NWSTX	Northwestern St. Croix
STX	SSTX	Southern St. Croix
STTSJ	EDGE	Edge
STTSJ	MSR	Mid-shelf Reef
STTSJ	SLRK	Sail Rock
STTSJ	STJ	St. John
STTSJ	STT	St. Thomas

Table 24. Management.

REGION	MANAGEMENT_NR	MANAGEMENT_NAME
STX	BUIS	Buck Island Reef National Monument
STX	EEMP	St. Croix East End Marine Park
STX	SARI	Salt River National Historical Park and Ecological Preserve
STTSJ	STEER	St. Thomas East End Reserves
STTSJ	VICR	Virgin Islands Coral Reef National Monument
STTSJ	VIIS	Virgin Islands National Park
STX, STTSJ	OPEN	All non-managed areas

Table 25. DEPSTRAT Descriptions.

DEPSTRAT	DESCRIPTION
SHLW	Shallow; 0–11.9 meters (0–39 ft) depth
DEEP	Deep; 12–30 meters (39.3–98.4 ft) depth

Table 26. STRAT Descriptions.

STRAT	DESCRIPTION
AGRF_DEEP	Aggregate reef deep
AGRF_SHLW	Aggregate reef shallow
BDRK_DEEP	Bedrock deep
BDRK_SHLW	Bedrock shallow
HARD_DEEP	Hard (unknown) deep
HARD_SHLW	Hard (unknown) shallow
PTRF_DEEP	Patch reef (Aggregate and individual) deep
PTRF_SHLW	Patch reef (Aggregate and individual) shallow
PVMT_DEEP	Pavement deep
PVMT_SHLW	Pavement shallow
SCR_DEEP	Scattered coral and rock deep
SCR_SHLW	Scattered coral and rock shallow

Literature Cited

Kendall, M. S., C. R. Kruer, K. R. Buja, J. D. Christensen, M. Finkbeiner, R. A. Warner, and M. E. Monaco. 2001. Methods used to map the benthic habitats of Puerto Rico and the U.S. Virgin Islands. NOAA Technical Memorandum, Vol. 152, Silver Spring, Maryland.

Appendix C. Comparison Area (m^2) Tables for Mapped Hardbottom and Survey Domain

Table 27. Florida Keys comparison between mapped HB and sample frame coverage area (m2) and number of PSUs (grid cells) for Biscayne and Upper Keys.

Stratum	Cross-Shelf Zone	Depth/Rugosity	Biscayne			Upper Keys		
			# cells	cell area (m^2)	Mapped HB area (m^2)	# cells	cell area (m^2)	Mapped HB area (m^2)
S01	Inshore Patch	Shallow/All relief	1,643	4,107,500	1,097,256	60	150,000	108,247
S02	Mid-channel Patch	Shallow/Low relief	15,408	38,520,000	7,871,332	7,574	18,935,000	2,594,468
S03	Mid-channel Patch	Shallow/High relief	3,805	9,512,500	4,467,535	496	1,240,000	386,102
S04	Mid-channel Patch	Shallow/Unknown	1,833	4,582,500	361,914	3,236	8,090,000	758,644
S05	Offshore Patch/Forereef	Shallow/Low relief	11,387	28,467,500	10,654,857	33,294	83,235,000	23,314,906
S06	Offshore Patch/Forereef	Shallow/High relief	5,648	14,120,000	12,612,685	6,319	15,797,500	13,202,026
S07	Offshore Patch/Forereef	Shallow/Unknown	92	230,000	50,826	1,088	2,720,000	1,416,617
S08	Offshore Patch/Forereef	Moderate/Low relief	2,650	6,625,000	1,766,610	1,746	4,365,000	1,490,321
S09	Offshore Patch/Forereef	Moderate/High relief	1,953	4,882,500	3,909,373	1,150	2,875,000	2,593,074
S10	Offshore Patch/Forereef	Moderate/Unknown	3,667	9,167,500	5,812,872	7,346	18,365,000	11,855,973
S11	Forereef	Deep/All relief	3,089	7,722,500	4,122,224	5,052	12,630,000	2,796,589
TOTAL	–	–	51,175	127,937,500	52,727,483	67,361	168,402,500	60,516,966

Table 28. Florida Keys comparison between mapped HB and sample frame coverage area (m^2) and number of PSUs (grid cells) for Upper-Mid, and Middle Keys.

Stratum	Cross-Shelf Zone	Depth/Rugosity	Upper-Mid Transition			Middle Keys		
			# cells	cell area (m^2)	Mapped HB area (m^2)	# cells	cell area (m^2)	Mapped HB area (m^2)
S01	Inshore Patch	Shallow/All relief	1,308	3,270,000	2,345,266	924	2,310,000	1,025,187
S02	Mid-channel Patch	Shallow/Low relief	1,251	3,127,500	777,203	379	947,500	493,437
S03	Mid-channel Patch	Shallow/High relief	59	147,500	124,155	136	340,000	254,630
S04	Mid-channel Patch	Shallow/Unknown	818	2,045,000	337,428	4,996	12,490,000	3,566,867
S05	Offshore Patch/Forereef	Shallow/Low relief	12,269	30,672,500	10,433,608	18,833	47,082,500	16,721,067
S06	Offshore Patch/Forereef	Shallow/High relief	1,326	3,315,000	2,930,860	1,298	3,245,000	2,505,769
S07	Offshore Patch/Forereef	Shallow/Unknown	1,039	2,597,500	1,181,226	3,255	8,137,500	3,133,921
S08	Offshore Patch/Forereef	Moderate/Low relief	851	2,127,500	759,727	1,185	2,962,500	762,255
S09	Offshore Patch/Forereef	Moderate/High relief	777	1,942,500	1,765,363	131	327,500	240,414
S10	Offshore Patch/Forereef	Moderate/Unknown	2,924	7,310,000	4,377,527	8,216	20,540,000	9,878,315
S11	Forereef	Deep/All relief	3,458	8,645,000	2,544,819	3,826	9,565,000	2,810,299
TOTAL			26,080	65,200,000	27,577,181	43,179	107,947,500	41,392,160

Table 29. Florida Keys comparison between mapped HB and sample frame coverage area (m2) and number of PSUs (grid cells) for the Lower Keys.

Stratum	Cross-Shelf Zone	Depth/Rugosity	Lower Keys		
			# cells	cell area (m^2)	Mapped HB area (m^2)
S01	Inshore Patch	Shallow/All relief	2,804	7,010,000	4,512,714
S02	Mid-channel Patch	Shallow/Low relief	621	1,552,500	431,887
S03	Mid-channel Patch	Shallow/High relief	322	805,000	556,627
S04	Mid-channel Patch	Shallow/Unknown	19,979	49,947,500	16,952,347
S05	Offshore Patch/Forereef	Shallow/Low relief	22,293	55,732,500	20,705,678
S06	Offshore Patch/Forereef	Shallow/High relief	5,880	14,700,000	12,758,973
S07	Offshore Patch/Forereef	Shallow/Unknown	5,608	14,020,000	8,440,483
S08	Offshore Patch/Forereef	Moderate/Low relief	3,362	8,405,000	1,595,217
S09	Offshore Patch/Forereef	Moderate/High relief	2,107	5,267,500	4,706,139
S10	Offshore Patch/Forereef	Moderate/Unknown	11,288	28,220,000	16,669,016
S11	Forereef	Deep/All relief	8,322	20,805,000	11,005,190
TOTAL	–	–	82,586	206,465,000	98,334,270

Table 30. St. John/St. Thomas comparison between mapped HB and sample frame coverage area (m2) and number of PSUs (grid cells) for management zones (Virgin Islands National Park [VIIS], Virgin Islands Coral Reef National Monument [VICR] and St. Thomas East End Marine Park [EEMP] and open waters.

Depth, Habitat	VIIS			VICR			STEER			Open		
–	# cells	cell area (m^2)	Mapped HB area (m^2)	# cells	cell area (m^2)	Mapped HB area (m^2)	# cells	cell area (m^2)	Mapped HB area (m^2)	# cells	cell area (m^2)	Mapped HB area (m^2)
Shallow, Bedrock	377	942,500	687,789	63	157,500	92,612	254	635,000	507,018	2,832	7,080,000	5,833,673
Deep, Aggregate Reef	359	897,500	582,072	175	437,500	253,074	122	305,000	186,439	2,678	6,695,000	5,243,089
Deep, Hard	982	2,455,000	367,577	493	1,232,500	71,457	0	0	0	17,233	43,082,500	10,979,322
Deep, Patch Reef	182	455,000	144,812	182	455,000	234,437	49	122,500	68,541	1,105	2,762,500	1,245,109
Deep, Pavement	790	1,975,000	1,220,003	807	2,017,500	1,614,673	153	382,500	264,322	9,423	23,557,500	16,390,508
Deep, Scattered Coral/Rock	67	167,500	42,273	79	197,500	45,868	26	65,000	44,064	2,332	5,830,000	2,326,439
Shallow, Aggregate Reef	383	957,500	817,932	110	275,000	217,360	252	630,000	559,642	1,687	4,217,500	3,685,890
Shallow, Hard	24	60,000	60,000	0	0	0	0	0	0	241	602,500	88,608
Shallow, Patch Reef	122	305,000	191,487	45	112,500	38,876	84	210,000	164,444	171	427,500	322,775
Shallow, Pavement	1,180	2,950,000	2,588,188	90	225,000	196,861	332	830,000	713,453	3,852	9,630,000	8,739,764
Shallow, Scattered Coral/Rock	248	620,000	360,625	44	110,000	64,797	101	252,500	123,806	736	1,840,000	1,478,831

Depth, Habitat	VIIS			VICR			STEER			Open		
–	# cells	cell area (m^2)	Mapped HB area (m^2)	# cells	cell area (m^2)	Mapped HB area (m^2)	# cells	cell area (m^2)	Mapped HB area (m^2)	# cells	cell area (m^2)	Mapped HB area (m^2)
TOTAL	4,714	11,785,000	7,062,759	2,088	5,220,000	2,830,015	1,373	3,432,500	2,631,729	42,290	105,725,000	56,334,008

Table 31. St. Croix comparison between mapped HB and sample frame coverage area (m2) and number of PSUs (grid cells) for management zones (Buck Island Coral Reef National Monument [BUIS], Salt River Historical and Ecological Preserve [SARI] and East End Marine Park [EEMP]) and open waters.

Depth, Habitat	BUIS			SARI			EEMP			Open		
–	# cells	cell area (m^2)	Mapped HB area (m^2)	# cells	cell area (m^2)	Mapped HB area (m^2)	# cells	cell area (m^2)	Mapped HB area (m^2)	# cells	cell area (m^2)	Mapped HB area (m^2)
Shallow, Bedrock	9	22,500	14,734	31	77,500	67,886	304	760,000	381,448	891	2,227,500	1,652,450
Deep, Aggregate Reef	18	45,000	36,553	19	47,500	37,172	449	1,122,500	1,034,622	2,101	5,252,500	4,741,955
Deep, Hard	0	0	0	3	7,500	992	33	82,500	8,709	1,231	3,077,500	98,734
Deep, Patch Reef	649	1,622,500	1,532,411	0	0	0	191	477,500	359,131	256	640,000	640,000
Deep, Pavement	1,785	4,462,500	4,080,256	80	200,000	199,553	22,956	57,390,000	56,147,530	28,217	70,542,500	69,852,971
Deep, Scattered Coral/Rock	161	402,500	282,521	8	20,000	20,000	2,361	5,902,500	5,702,604	3,270	8,175,000	8,015,966
Shallow, Aggregate Reef	223	557,500	536,214	46	115,000	99,795	1,120	2,800,000	2,358,471	1,235	3,087,500	2,659,154
Shallow, Hard	0	0	0	4	10,000	0	0	0	0	95	237,500	12,539
Shallow, Patch Reef	1,012	2,530,000	2,411,443	4	10,000	6,679	179	447,500	264,878	613	1,532,500	1,163,506
Shallow, Pavement	3,196	7,990,000	7,761,681	305	762,500	750,642	4,883	12,207,500	11,379,535	13,637	34,092,500	31,538,859

Depth, Habitat	BUIS			SARI			EEMP			Open		
–	# cells	cell area (m^2)	Mapped HB area (m^2)	# cells	cell area (m^2)	Mapped HB area (m^2)	# cells	cell area (m^2)	Mapped HB area (m^2)	# cells	cell area (m^2)	Mapped HB area (m^2)
Shallow, Scattered Coral/Rock	381	952,500	720,380	0	0	0	245	612,500	507,559	495	1,237,500	1,114,776
TOTAL	7,434	18,585,000	17,376,193	500	1,250,000	1,182,718	32,721	81,802,500	78,144,487	52,041	130,102,500	121,490,911