Sampling Design Protocol for the U.S. Caribbean and Flower Garden Banks National Marine Sanctuary: 2013 to 2015

National Coral Reef Monitoring Program (NCRMP)
Coral Reef Conservation Program (CRCP), National Oceanic and Atmospheric Administration

Introduction

The National Coral Reef Monitoring Program (NCRMP) provides a biennial ecological characterization at a broad spatial scale of general reef condition for reef fishes, corals and benthic habitat (*i.e.*, fish species composition/density/size, benthic cover, and coral density/size/condition). This report describes the sampling designs used to monitor coral reefs and associated biological communities around Puerto Rico, the US Virgin Islands (USVI) and the Flower Garden Banks National Marine Sanctuary (FGBNMS) as part of NCRMP.

NCRMP began in 2013 and over the years the sampling design has changed to integrate new information, achieve new objectives and develop more precise measurements. This report is divided by year and jurisdiction to describe each sampling design. In general sampling for each jurisdiction occurs biennially with sampling in Puerto Rico, and the USVI and Flower Garden Banks occurring in alternating years.

2013 St. Thomas and St. John, USVI

A stratified random sampling design was used to allocate sites for fish and coral surveys around the islands of St. John and St. Thomas, USVI in 2013. The design was disproportionate to size in order to increase sample sizes for important subgroups within the survey population. The sample frame consisted of regularly-spaced 50 by 50 meter sampling units distributed across shallow water coral reef habitats. The frame was created in ArcGIS v.9.3 using the Fishnet tool and was projected in the NAD83 UTM20N projection. The grid comprised coral reefs and other hardbottom habitats surrounding the island islands of St. John and St. Thomas to a depth of 30 meters. All sample units which were inaccessible or deemed hazardous were excluded. The sample frame extended to the shelf edge to the south and the territorial sea boundary to the north and east. The western edge extended to -65.15 degrees.

The locations of hardbottom habitats were defined using benthic habitat maps of St Thomas and St John (Kendall et al., 2001; Zitello et al., 2009; Costa et al., 2009), and a predicted model of hardbottom habitats (unpublished data, 2013). The most recent map was used to assign benthic habitat information to sample units when maps overlapped. Hardbottom habitats consisted of the following types: linear reefs, patch reefs, colonized bedrock, colonized pavement, scattered coral/rock in unconsolidated sediments and predicted hardbottom. Reef rubble and rhodolith habitats were not included as hardbottom habitats. All sampling units were classified by a single habitat type and in units with multiple habitat types the grid unit was assigned the highest priority habitat that made up a minimum of 5% of the area of the unit. Habitat type was prioritized in the following descending order: 1) aggregate reef, 2) patch reef, 3) bedrock, 4) pavement, 5) scattered coral/rock, and 6) predicted hardbottom.

All sample units were given a depth, biotope and administrative zone classification. Sample unit depth was assigned the depth taken from the best available bathymetry data at the centroid of the unit. Bathymetry data were derived from three sources in the following hierarchical order: NOAA LIDAR surveys, NOAA multibeam sonar surveys and the NOAA coastal relief model. Sample units between 0 m and 12 m were classified as shallow and units between 12 m and 30 m were classified as deep. Sample units with depths less than 0 m (i.e. above sea level) were excluded (this occurred when depth data was inaccurate). In rare instances units with uncertain bathymetry data were reclassified using information from aerial imagery and NOAA nautical charts.

Units were classified into one of the four following administrative zones: (1) VICR – the Virgin Islands Coral Reef National Monument, (2) VINP – the Virgin Islands National Park, (3) STEER – the St. Thomas East End Reserve, (4) OPEN – the remaining units. Units were also classified into one of the four following biotopes independently of the administration zone selection process: 1) MSR – Mid-shelf Reef, 2) SLRK – the area around Sail Rock, 3) STJ – nearshore St. John, and 4) STT – nearshore St. Thomas.

Strata were developed from all combinations of habitat types, depth classes, administrative zones and biotopes. Fifty-six (56) different mutually-exclusive strata were defined and used to stratify the sample frame (Figure 1). Sample allocation was developed in an adaptive manner to achieve consensus among monitoring partners. Allocations began as proportional to area, then were manually adjusted to ensure a minimum of 2 sample units were chosen from each stratum and greater emphasis was given to VICR, VINP and STEER. Units in the SLRK biotope were excluded from this process, because of uncertainty in accompanying habitat and depth data and the unknown effort required to visit this strata. Eight (8) units were purposively selected in the SLRK biotope. Before implementation the sampling design was reviewed and agreed upon by representatives from the National Park Service and Southeast Fisheries Service, as well as NCCOS scientists.

In order to achieve the desired results the allocation proceeded in two phases. First samples were allocated to each administrative zone. Then sampling units were allocated to each stratum according to the following formula:

$$n_h = n_{h\_min} + n_{admin\_remainder} [N_h / sum(N_h]$$

where $n_{h\_min} = 2$, $n_{admin\_remainder}$ = the number of samples allocated to an administrative zone after the minimum sample size requirement is met, and N_h = number of sample units in stratum h.

The BioGeo sampling tool (http://coastalscience.noaa.gov/projects/detail?key=185) was used to select 250 samples from the sample frame using the strata and allocation scheme described above. These 250 samples formed the planned primary sample unit set. An auxiliary set of sample units was also generated from the sample frame using the same strata and allocation scheme. If a unit from the primary sample unit set was found to inaccessible or hazardous, a new sample unit from the auxiliary set was randomly chosen from within the same strata to replace the unobtainable unit. If time and effort permitted, a new sample unit from the auxiliary set was randomly chosen at the discretion of the field coordinator.

The geographic coordinates of planned sample units were defined by the Easting and Northing coordinates of sample unit centroids in the NAD83 UTM20N projection. Coordinates were provided to field coordinators and distributed among dive teams to implement NCRMP Caribbean-Gulf of Mexico Field Protocols (http://coastalscience.noaa.gov/projects/detail?key=180). In all field collections the surveyed areas do not exhaustively cover the sample unit. Intrinsically this means a second stage of non-exhaustive sampling occurs within the sample unit. Field protocols address this second stage of sampling using a random area selection process. For instance, belt transects are randomly positioned to extend from the centroid in a sample unit.

Sample weights for each sample unit are defined by the reciprocal of its probability of selection. Since a stratified random sampling design was implemented the probability of selection is the number units sampled within a stratum divided by the total number units within a stratum. The second stage of selection is not integrated into sampling weights, because they are identical among units for each field data collection method and only relative metrics are calculated. If absolute abundance measures are desired from the sample, second stage sample weights must be calculated and included. All sample weights are greater than or equal to 1, and all units within the same stratum have identical sample weights. The sample weights act as inflation factors to represent the number of units in the survey population that are accounted for by the sample unit to which the weight is assigned. The sum of the sample weights is equal to the total number of sample units in the target population.

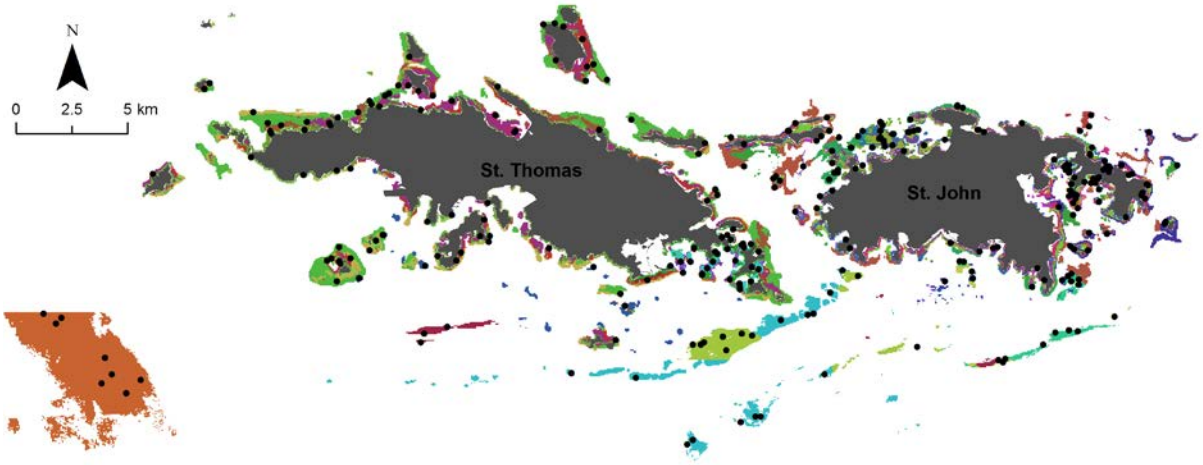

Figure 1. Map of strata used to allocate sites for fish and coral surveys around the islands of St. John and St. Thomas, USVI in 2013. Surveyed sites are represented by black dots.

2013 Flower Garden Banks

A stratified random sampling design was used to allocate sites for fish and coral surveys on East and West Flower Garden Banks. The design was proportionate to strata sizes. The sample frame consisted of regularly-spaced 50 by 50 meter sampling units distributed across the shallow coral reef (depth range 18-30 m). The frame was created in ArcGIS v.9.3 using the Fishnet tool and was projected in the NAD83 UTM15N projection. The grid comprised coral reef and relief features (high and low) to depths of 30 m.

The original habitat map for the shallow portion of the sanctuary was developed by Caldow et al. (2009) and further refined by Clark et al. (2014). The majority of the shallow reef (18-30 m) is high relief and structurally complex, with some low relief and low complexity areas in deeper water. Each grid within the sampling frame was classified by bank (either East or West) and the relief class (high or low) with the greatest area.

All sample units were given a depth, biotope and administrative zone classification. All sampled zones are within the FGBNMS administrative area. Sample unit depth was assigned the depth taken from the best available bathymetry data at the centroid of the unit. High resolution data exists for the shallow coral reefs (<1 m). Overall there were four sampling strata within the sampling domain: West Bank high relief, West Bank low relief, East Bank high relief, East Bank low relief.

The BioGeo sampling tool (http://coastalscience.noaa.gov/projects/detail?key=185) was used to select 75 samples from the sample frame using the strata and allocation scheme described above. These samples formed the primary sample unit set. An auxiliary set of sample units was also generated from the sample frame using the same strata and allocation scheme. If a unit from the primary sample unit set was found to be inaccessible or hazardous, a new sample unit from the auxiliary set was randomly chosen from within the same strata to replace the unobtainable unit. If time and effort permitted, a new sample unit from the auxiliary set was randomly chosen at the discretion of the field coordinator.

The geographic coordinates of planned sample units were defined by the Easting and Northing coordinates of sample unit centroids in the NAD83 UTM15N projection. Coordinates were provided to field coordinators and distributed among dive teams to implement NCRMP Field Protocols (http://coastalscience.noaa.gov/projects/detail?key=180). At each primary sample unit fish and line-point intercept benthic protocols were implemented. Approximately 50% of the primary sample units were randomly selected to include coral demographic surveys conducted in accordance with NCRMP Field Protocols.

In all field collections the surveyed areas do not exhaustively cover the sample unit. Intrinsically this means a second stage of non-exhaustive sampling occurs within the sample unit. Field protocols address this second stage of sampling using a random area selection process. For instance, belt transects are randomly positioned to extend from the centroid in a sample unit.

Sample weights for each sample unit are defined by the reciprocal of its probability of selection. Since a stratified random sampling design was implemented the probability of selection is the number units sampled within a stratum divided by the total number units within a stratum. The second stage of selection is not integrated into sampling weights, because they are identical among units for each field data collection method and only relative metrics are calculated. If absolute abundance measures are desired from the sample, second stage sample weights must be calculated and included. All sample weights are greater than or equal to 1, and all units within the same stratum have identical sample weights. The sample weights act as inflation factors to represent the number of units in the survey population that are accounted for by the sample unit to which the weight is assigned. The sum of the sample weights is equal to the total number of sample units in the target population.

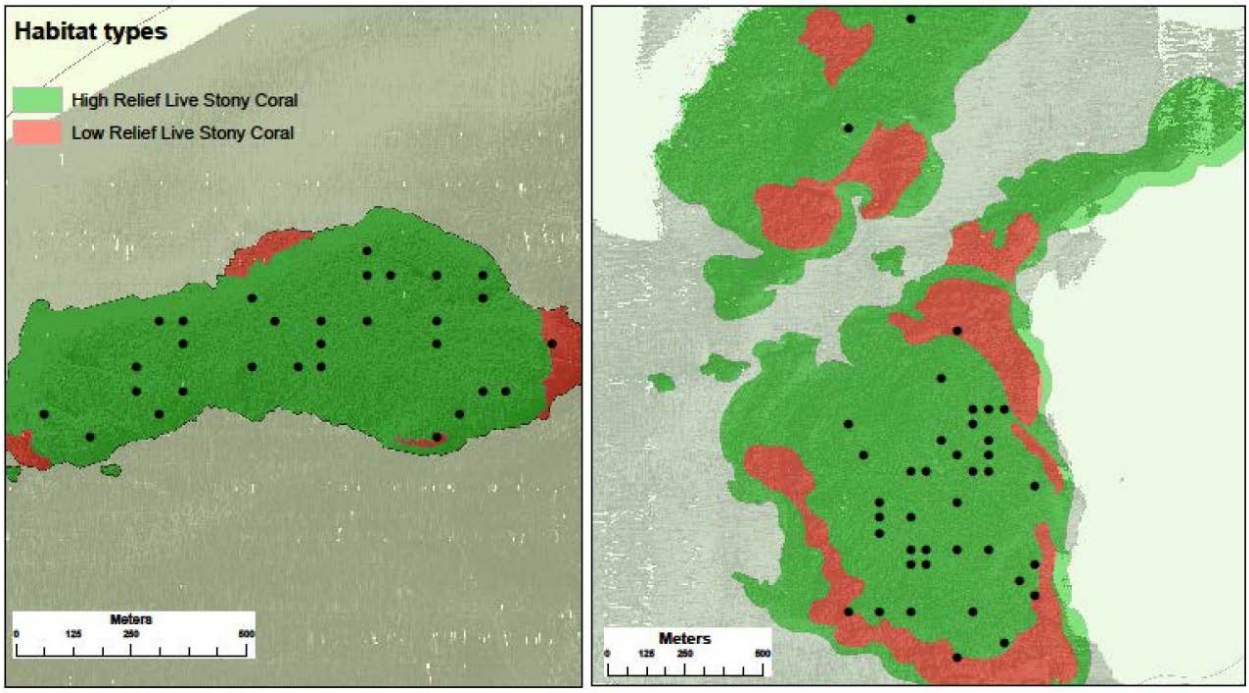

Figure 2. Map of strata used to allocate sites for fish and coral surveys around East and West Banks of the Flower Garden Banks National Marine Sanctuary during 2013. Surveyed sites are represented by black dots.

2014 Puerto Rico – includes entire island perimeter and islands of Vieques, Culebra and Mona

A stratified random sampling design was used to choose sites for fish and coral surveys around Puerto Rico in 2014. The design was disproportionate to size in order to increase sample sizes for important subgroups within the survey population. The sample frame consisted of regularly-spaced 50 by 50 meter sampling units distributed across shallow water coral reef habitats.

The frame was created in ArcGIS v.9.3 using the Fishnet tool and was projected in the NAD83 UTM19N projection. The grid comprised coral reefs and other hardbottom habitats surrounding the island islands of Puerto Rico, Vieques, Culebra and Mona to a depth of 30 meters. All sample units which were inaccessible or deemed hazardous were excluded. The sample frame extended to the territorial sea boundary to the north, south and west. The eastern edge extended to -65.15 degrees.

The locations of hardbottom habitats were defined using benthic habitat maps of St Thomas and St John (Kendall et al. 2001, Bauer et al. 2008). The most recent map was used to assign benthic habitat information to sample units when maps overlapped. Hardbottom habitats consisted of the following types: aggregate reefs, patch reefs, colonized bedrock, colonized pavement, and scattered coral/rock in unconsolidated sediments. Reef rubble and rhodolith habitats were not included as hardbottom habitats. Any unit with less than 10% hardbottom habitat combined among all habitat categories was excluded. All sampling units were classified by a single habitat type and in units with multiple habitat types the sample unit was assigned the habitat type with the greatest amount of area within its borders.

All sample units were given a depth, biotope and administrative zone classification. Sample unit depth was assigned the depth taken from the best available bathymetry data at the centroid of the unit. Bathymetry data were derived from three sources in the following hierarchical order: NOAA LIDAR surveys, NOAA multibeam sonar surveys and the NOAA coastal relief model. Sample units between 0 m and 12 m were classified as shallow and units between 12 m and 30 m were classified as deep. Sample units with depths less than 0 m (i.e. above sea level) were excluded (this occurred when depth data was inaccurate). In rare instances units with uncertain bathymetry data were reclassified using information from aerial imagery and NOAA nautical charts.

Units were classified into one of the five following administrative zones: (1) CLP – the Canal Luis Peña Nature Reserve, (2) ID – the Isla de Desecheo Marine Reserve, (3) IM – the Isla de Mona Natural Reserve, (4) TPR - Tres Palmas de Rincón Marine Reserve, and (5) OPEN – the remaining units. Units were also classified into one of the three following biotopes independently of the administration zone selection process: 1) N – northern area of Puerto Rico, 2) E – eastern area of Puerto Rico, and 3) SW – southwestern area of Puerto Rico.

Strata were developed from all combinations of habitat types, depth classes, administrative zones and biotopes. Forty-six (46) different mutually-exclusive strata were defined and used to stratify the sample frame (Figure 2). Sample allocation was developed in an adaptive manner to achieve consensus among monitoring partners. Allocations began as proportional to area, then were manually adjusted to ensure a minimum of 2 sample units were chosen from each stratum and sites were distributed uniformly across the sample frame. Before implementation the sampling

design was reviewed and agreed upon by representatives from the National Park Service and Southeast Fisheries Service, as well as NCCOS scientists.

Sampling units were allocated to each stratum according to the following formula:

$$n_h = n_{h\_min} + n_{admin\_remainder} [N_h / sum(N_h]$$

where $n_{h\_min} = 2$, $n_{admin\_remainder}$ = the number of samples allocated to an administrative zone after the minimum sample size requirement is met, and N_h = number of sample units in stratum h.

The BioGeo sampling tool (http://coastalscience.noaa.gov/projects/detail?key=185) was used to select 250 samples from the sample frame using the strata and allocation scheme described above. These 250 samples formed the planned primary sample unit set. An auxiliary set of 125 sample units was also generated from the sample frame using the same strata and allocation scheme. If a unit from the primary sample unit set was found to be inaccessible or hazardous, a new sample unit from the auxiliary set was randomly chosen from within the same strata to replace the unobtainable unit. If time and effort permitted, a new sample unit from the auxiliary set was randomly chosen at the discretion of the field coordinator.

The geographic coordinates of planned sample units were defined by the Easting and Northing coordinates of sample unit centroids in the NAD83 UTM19N projection. Coordinates were provided to field coordinators and distributed among dive teams to implement NCRMP Caribbean-Gulf of Mexico Field Protocols (http://coastalscience.noaa.gov/projects/detail?key=180). In all field collections the surveyed areas do not exhaustively cover the sample unit. Intrinsically this means a second stage of non-exhaustive sampling occurs within the sample unit. Field protocols address this second stage of sampling using a random area selection process. For instance, belt transects are randomly positioned to extend from the centroid in a sample unit.

Sample weights for each sample unit are defined by the reciprocal of its probability of selection. Since a stratified random sampling design was implemented the probability of selection is the number units sampled within a stratum divided by the total number units within a stratum. The second stage of selection is not integrated into sampling weights, because they are identical among units for each field data collection method and only relative metrics are calculated. If absolute abundance measures are desired from the sample, second stage sample weights must be calculated and included. All sample weights are greater than or equal to 1, and all units within the same stratum have identical sample weights. The sample weights act as inflation factors to represent the number of units in the survey population that are accounted for by the sample unit to which the weight is assigned. The sum of the sample weights is equal to the total number of sample units in the target population.

Figure 3. Map of strata used to allocate sites for fish and coral surveys around Puerto Rico in 2014. Surveyed sites are represented by black dots.

2015 USVI – includes the islands of St. Thomas, St. John and St. Croix

A stratified random sampling design was used to allocate sites for fish and coral surveys around the islands of St. Thomas, St. John and St. Croix, USVI in 2015. The design was disproportionate to size in order to increase sample sizes for important subgroups within the survey population. The sample frame consisted of regularly-spaced 50 by 50 meter sampling units distributed across shallow water coral reef habitats. For practical purposes the sample frame was divided into two parts, a northern part for St. Thomas and St. John, and a southern part for St. Croix. The northern part of the sample frame was similar but not identical to the frame used in 2013. Differences reflect updates to benthic habitat and depth information.

The frame was created in ArcGIS v. 10.1 using the Fishnet tool and was projected in the NAD83 UTM20N projection. The grid comprised coral reefs and other hardbottom habitats surrounding the island islands of St. Thomas, St. John and St. Croix, USVI to a depth of 30 meters. All sample units which were inaccessible or deemed hazardous were excluded. The sample frame extended to -65.15 degrees to the west of St. Thomas or either to US jurisdictional boundaries or the limit of 30 m hardbottom habitats in other bearings. Based on past missions where several shallow sites were found to be inaccessible all sample units with centroids within 5 m of shore were excluded.

The locations of hardbottom habitats were defined using multiple benthic habitat maps of St. Thomas, St. John and St. Croix (Kendall et al., 2001; Zitello et al., 2009; Costa et al., 2009; Costa et al., 2012; Costa et al., 2013), and a predicted model of hardbottom habitats (unpublished data, 2013). The most recent map was used to assign benthic habitat information to sample units when maps overlapped. Hardbottom habitats consisted of the following types: linear reefs, patch reefs, colonized bedrock, colonized pavement, scattered coral/rock in unconsolidated sediments and predicted hardbottom. Reef rubble and rhodolith habitats were not included as hardbottom habitats. Any unit with less than 10% hardbottom habitat combined among all habitat categories was excluded. All sampling units were classified by a single habitat type and in units with multiple habitat types the sample unit was assigned the habitat type with the greatest amount of area within its borders.

All sample units were given a depth, biotope and administrative zone classification. Sample unit depth was assigned the depth taken from the best available bathymetry data at the centroid of the unit. Bathymetry data were derived from three sources in the following hierarchical order: NOAA LIDAR surveys, NOAA multibeam sonar surveys and the NOAA coastal relief model. Sample units between 0 m and 12 m were classified as shallow and units between 12 m and 30 m were classified as deep. Sample units with depths less than 0 m (i.e. above sea level) were excluded (this occurred when depth data was inaccurate). In rare instances units with uncertain bathymetry data were reclassified using information from aerial imagery and NOAA nautical charts. All bedrock strata were classified as shallow.

Units were classified into one of the seven following administrative zones: (1) VICR – the Virgin Islands Coral Reef National Monument, (2) VIIS – the Virgin Islands National Park, (3) STEER – the St. Thomas East End Reserve, (4) BUIS – The Buck Island Reef National Monument, (5) EEMP – the East End Marine Park, (6) SARI – Salt River Bay National Historic Park and Ecological Preserve, and (7) OPEN – the remaining units.

Units were also classified into one of the four following biotopes independently of the administration zone selection process: 1) MSR – the mid-shelf reefs off St. Thomas and St. John, 2) SLRK – the Sail Rock area, 3) STJ – nearshore St. John, 4) STT – nearshore St. Thomas, 5) LANG – the Lang Bank area, 6) ESTX – the eastern side of St Croix consisting of BUIS and EEMP, 7) NWSTX – the northern and western sides of St Croix, 8) SSTX – the southern side of St Croix. The precise boundaries of biotopes attempt to overlap distinctions in administrative zones, depth classes and benthic habitat types.

Strata were developed from all combinations of habitat types, depth classes, administrative zones and biotopes. Units within very small strata (N<10) were removed from the sample frame. In St. Thomas and St John five strata with a total of 25 units were removed, and in St. Croix one stratum with a total of four units was removed. Sixty-three (63) and forty-three (43) different mutually-exclusive strata were defined and used to stratify the sample frame in the St. Thomas and St. John area, and the St. Croix area, respectively (Figure 3).

Sample allocation was developed in an adaptive manner to achieve consensus among monitoring partners. Allocations began as proportional to area, then were manually adjusted to ensure a minimum of 2 sample units were chosen from each stratum and greater emphasis was given to VICR, VIIS, STEER, BUIS, SARI and EEMP. Units in the SLRK and EDGE biotope were excluded from this process, because of uncertainty in accompanying habitat and depth data and the unknown effort required to visit these strata. Eleven (11) and four (4) units were purposively selected in the SLRK and EDGE biotopes, respectively.

Habitats were classified into two groups by expected relative levels of coral and fish metric variances. Expected metric variances were included in the optimal allocation process to guarantee strata with greater variance are sampled more than strata with lower variance. This was achieved by grouping scattered coral and rock in sand and bedrock together and assigning these habitats a relative standard deviation index equal to 1.0. All other habitat types were grouped together and given a relative standard deviation index equal to 1.5.

Before implementation the sampling design was reviewed and agreed upon by representatives from the National Park Service and Southeast Fisheries Service, as well as NCCOS scientists. The allocation proceeded in two phases. First samples were allocated to each administrative zone. Then sampling units were allocated to each stratum according to the following formula:

$$n_h = n_{h\_min} + n_{admin\_remainder}[(N_h * S_h) / sum(N_h * S_h]$$

where $n_{h\_min} = 2$, $n_{admin\_remainder}$ = the number of samples allocated to an administrative zone after the minimum sample size requirement is met, N_h = number of sample units in stratum h, and S_h = relative standard deviation index in stratum h.

The BioGeo sampling tool (http://coastalscience.noaa.gov/projects/detail?key=185) was used to select 250 samples from the sample frame using the strata and allocation scheme described above. These 250 samples formed the planned primary sample unit set. An auxiliary set of sample units was also generated from the sample frame using the same strata and allocation scheme. If a unit from the primary sample unit set was found to inaccessible or hazardous, a new sample unit from the auxiliary set was randomly chosen from within the same strata to replace

the unobtainable unit. If time and effort permitted, a new sample unit from the auxiliary set was randomly chosen at the discretion of the field coordinator.

The geographic coordinates of planned sample units were defined by the Easting and Northing coordinates of sample unit centroids in the NAD83 UTM20N projection. Coordinates were provided to field coordinators and distributed among dive teams to implement the NCRMP Caribbean-Gulf of Mexico Field Protocols (http://coastalscience.noaa.gov/projects/detail?key=180). In all field collections the surveyed areas do not exhaustively cover the sample unit. Intrinsically this means a second stage of non-exhaustive sampling occurs within the sample unit. Field protocols address this second stage of sampling using a random area selection process. For instance, belt transects are randomly positioned to extend from the centroid in a sample unit.

Sample weights for each sample unit are defined by the reciprocal of its probability of selection. Since a stratified random sampling design was implemented the probability of selection is the number units sampled within a stratum divided by the total number units within a stratum. The second stage of selection is not integrated into sampling weights, because they are identical among units for each field data collection method and only relative metrics are calculated. If absolute abundance measures are desired from the sample, second stage sample weights must be calculated and included. All sample weights are greater than or equal to 1, and all units within the same stratum have identical sample weights. The sample weights act as inflation factors to represent the number of units in the survey population that are accounted for by the sample unit to which the weight is assigned. The sum of the sample weights is equal to the total number of sample units in the target population.

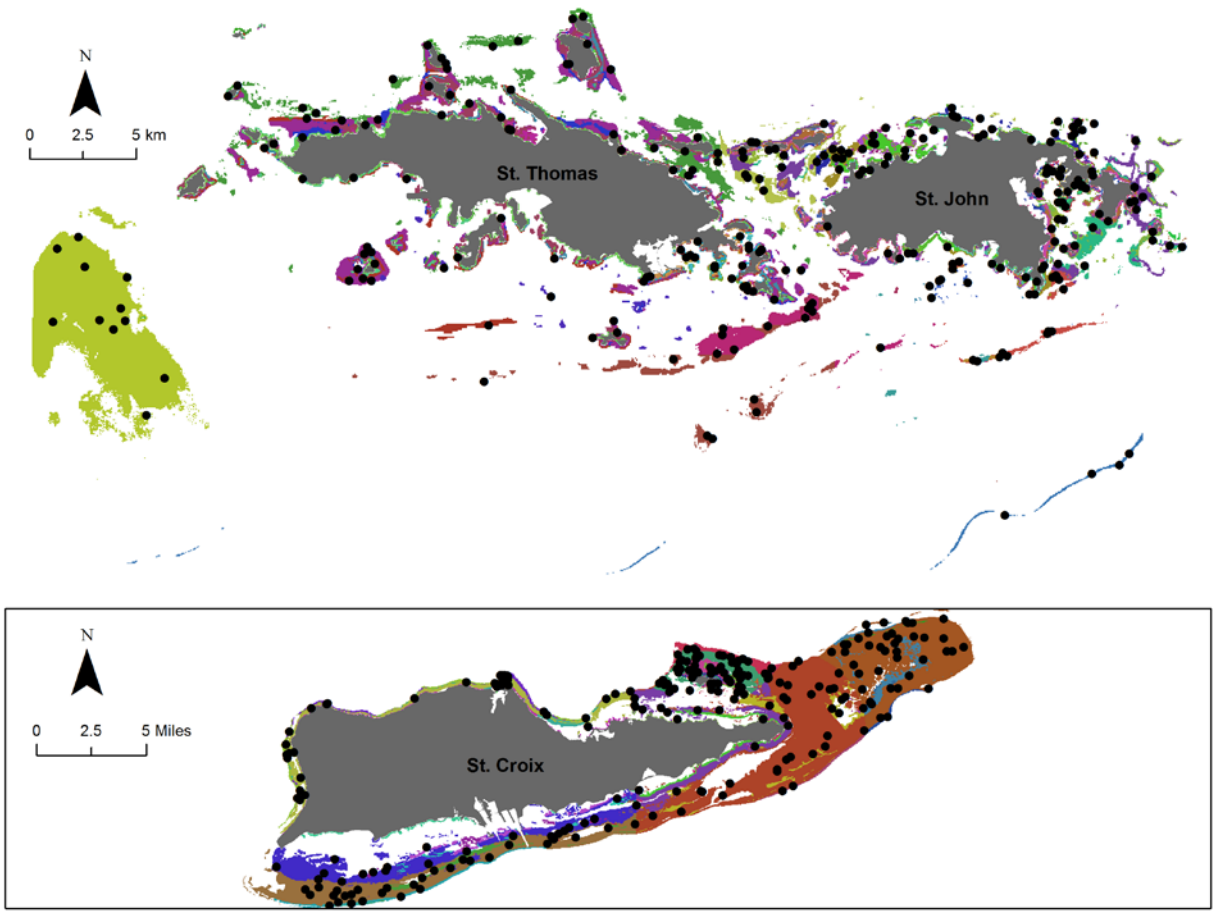

Figure 4. Map of strata used to allocate sites for fish and coral surveys around the islands of St. Thomas, St. John and St. Croix, USVI in 2015. Surveyed sites are represented by black dots.

2015 Flower Garden Banks

A stratified random sampling design was used to allocate sites for fish and coral surveys on East and West Flower Garden Banks. The design was proportionate to size of strata. The sample frame consisted of regularly-spaced 50 by 50 meter sampling units distributed across the shallow coral reef (18-30 m). The frame was created in ArcGIS v.9.3 using the Fishnet tool and was projected in the NAD83 UTM15N projection. The grid comprised coral reef and relief features (high and low) to depths of 30 m.

The original habitat map for the shallow portion of the sanctuary was developed by Caldow et al. (2009) and further refined by Clark et al. (2014). The majority of the shallow reef (18-30 m) is high relief and structurally complex, with some low relief and low complexity areas in deeper water. Each grid within the sampling frame was classified by bank (either East or West) and the relief class (high or low) with the greatest area.

All sample units were given a depth, biotope and administrative zone classification. All sampled zones are within the FGBNMS administrative area. Sample unit depth was assigned the depth taken from the best available bathymetry data at the centroid of the unit. High resolution data exists for the shallow coral reefs (<1 m). Overall there were four sampling strata within the sampling domain: West Bank high relief, West Bank low relief, East Bank high relief, East Bank low relief.

The BioGeo sampling tool (http://coastalscience.noaa.gov/projects/detail?key=185) was used to select 75 samples from the sample frame using the strata and allocation scheme described above. These samples formed the primary sample unit set. An auxiliary set of sample units was also generated from the sample frame using the same strata and allocation scheme. If a unit from the primary sample unit set was found to be inaccessible or hazardous, a new sample unit from the auxiliary set was randomly chosen from within the same strata to replace the unobtainable unit. If time and effort permitted, a new sample unit from the auxiliary set was randomly chosen at the discretion of the field coordinator.

The geographic coordinates of planned sample units were defined by the Easting and Northing coordinates of sample unit centroids in the NAD83 UTM15N projection. Coordinates were provided to field coordinators and distributed among dive teams to implement NCRMP Field Protocols (http://coastalscience.noaa.gov/projects/detail?key=180). At each primary sample unit fish and line-point intercept benthic protocols were implemented. Approximately 50% of the primary sample units were randomly selected to include coral demographic surveys conducted in accordance with NCRMP Field Protocols.

In all field collections the surveyed areas do not exhaustively cover the sample unit. Intrinsically this means a second stage of non-exhaustive sampling occurs within the sample unit. Field protocols address this second stage of sampling using a random area selection process. For instance, belt transects are randomly positioned to extend from the centroid in a sample unit.

Sample weights for each sample unit are defined by the reciprocal of its probability of selection. Since a stratified random sampling design was implemented the probability of selection is the number of units sampled within a stratum divided by the total number units within a stratum. The second stage of selection is not integrated into sampling weights, because they are identical

among units for each field data collection method and only relative metrics are calculated. If absolute abundance measures are desired from the sample, second stage sample weights must be calculated and included. All sample weights are greater than or equal to 1, and all units within the same stratum have identical sample weights. The sample weights act as inflation factors to represent the number of units in the survey population that are accounted for by the sample unit to which the weight is assigned. The sum of the sample weights is equal to the total number of sample units in the target population.

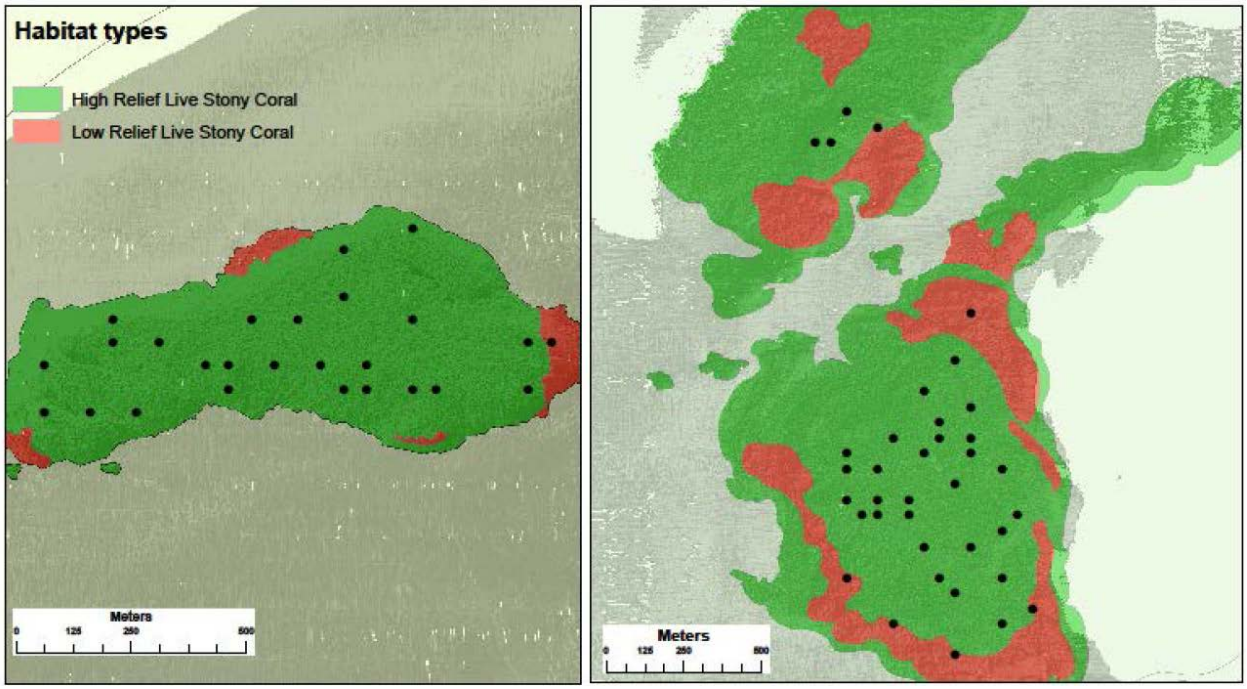

Figure 5. Map of strata used to allocate sites for fish and coral surveys around East and West Banks of the Flower Garden Banks National Marine Sanctuary during 2015. Surveyed sites are represented by black dots.

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