NOAA Technical Memorandum NMFS-SEFSC-641

# A PILOT, COOPERATIVE FISHERY-INDEPENDENT TRAP SURVEY OF SAINT CROIX, UNITED STATES VIRGIN ISLANDS

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## Introduction

The re-authorized Magnuson-Stevens Act requires that all US managed fisheries utilize biomass based annual catch limits (ACLs) to prevent overfishing. Ideally, quantitative stock assessments can be conducted to estimate abundance and management reference points (e.g., maximum sustainable yield, MSY) to develop ACLs. Stock assessment scientists, via the Southeast Data, Assessment and Review (SEDAR) stock assessment process, evaluated available data sources and assessment techniques available for the US Caribbean in January 2009 (see the SEDAR Procedures Workshop 3 report). The overall consensus was that data limitations preclude comprehensive stock assessments in the US Caribbean. As a result, staff members at NOAA's Southeast Fisheries Science Center (SEFSC), in conjunction with the Caribbean Fishery Management Council (CFMC), and state and territorial managers, have been working to evaluate and modify commercial and recreational data collection protocols. While improving fishery-dependent data is critical, most managers and scientists that are engaged in the stock assessment process in the US Caribbean support the development of new fishery-independent techniques to address the limitations of the fishery dependent data.

This report summarizes a cost-effective, fishery-independent survey program executed in 2010, which represents the first comprehensive spatial evaluation of relative fish abundance for any US Caribbean territory. This cooperative project employed the resources and knowledge of the local fishing communities and initiated collaborative communications between the stakeholders, scientists, and resource managers. Its successful completion demonstrates a survey concept that can be used to develop similar programs in other locations. Funding for this project was provided by NOAA's Coral Reef Conservation Program.

The main goals of this study were to:

1. Develop a statistically sound survey of the entire St. Croix continental shelf by integrating information from existing high resolution habitat mapping projects with local, historical fishing patterns
2. Using the above survey design, develop and execute a cooperative and cost-effective sampling program with the local fishing community that is transferable to other U.S. Caribbean regions.

3. Statistically analyze the data to (a) provide the first spatially comprehensive snapshot of relative reef fish abundances in the US Caribbean, (b) evaluate the spatial autocorrelation of St. Croix fish resources to determine the efficacy and efficiency of the survey design, and (c) determine the utility of the approach for future expansion.

## Methods

### *Scoping*

A series of formal and informal meetings were conducted by NOAA staff to communicate the goals of the project to stakeholders and management agencies, determine the interest of local groups in participating in this cooperative project, and gather advice for survey design. Meeting participants included local commercial and recreational fishers, including the St. Croix Commercial Fishermen's Association (SCCFA); and employees of the USVI territorial government agencies, including Department of Fish and Wildlife (DFW), Department of Environmental Enforcement (DEE), and Department of Coastal Zone Management (CZM); National Park Service (NPS) personnel responsible for the management of Buck Island Reef National Monument (BIRNM) and Salt River. Participants discussed a number of survey design and logistical considerations during the meetings, including trap type and size, bait, soak time, fishing depth, cost structure, fisher participation, avoidance of sensitive habitats, and permitting. Management agencies agreed to grant us access to all management zones across St. Croix, including East End Marine Park, BIRNM and Salt River, Lang Bank, and the Hovensa Security Zone.

### *Fishery-independent survey sampling design*

Following the planning meetings, we determined that approximately 600 stations could be sampled given financial and logistical constraints. We used two complimentary statistical designs, a stratified random design (SRD) and a spatially optimal design (SOD), to choose the location of the majority of stations. NOAA National Centers for Coastal Ocean Science (NCCOS) provided high resolution NOAA habitat maps. We used the maps to identify general bottom types as hard or soft-bottom, which we then classified on a finer scale. Fine scale hard-bottom habitat types included: hard-bottom coral patches (CP), CP with sand channels, aggregated patch reef (PR), linear reef, and scattered coral with unconsolidated pavement. Fine-scale soft-bottom habitat types included: macroalgae, sand, and seagrass.

We identified 400 station locations using the SRD (i.e. stratified across hard-bottom habitats, soft-bottom habitats, and areas open and closed to fishing) and 200 station locations based on a newly developed SOD. The SOD employed an algorithm that searched over a spatial grid that covered the entire fishable shelf of St. Croix. The algorithm iteratively identifies the location that would best fill in the spatial gaps of the existing samples, then assuming that this location has been added to the sample set, selects another location, and so on until the target of 600 total stations are selected (Figure 1). This method uses spatial autocorrelation (i.e. the property that samples close together are more alike than those further apart) to select samples that optimize the spatial coverage. Additional descriptions of the sampling methodology are included in Appendix A. We selected an additional 14 sampling stations located at preexisting fixed stations visually surveyed by other projects, but we did not consider these stations for the analysis presented in this report.

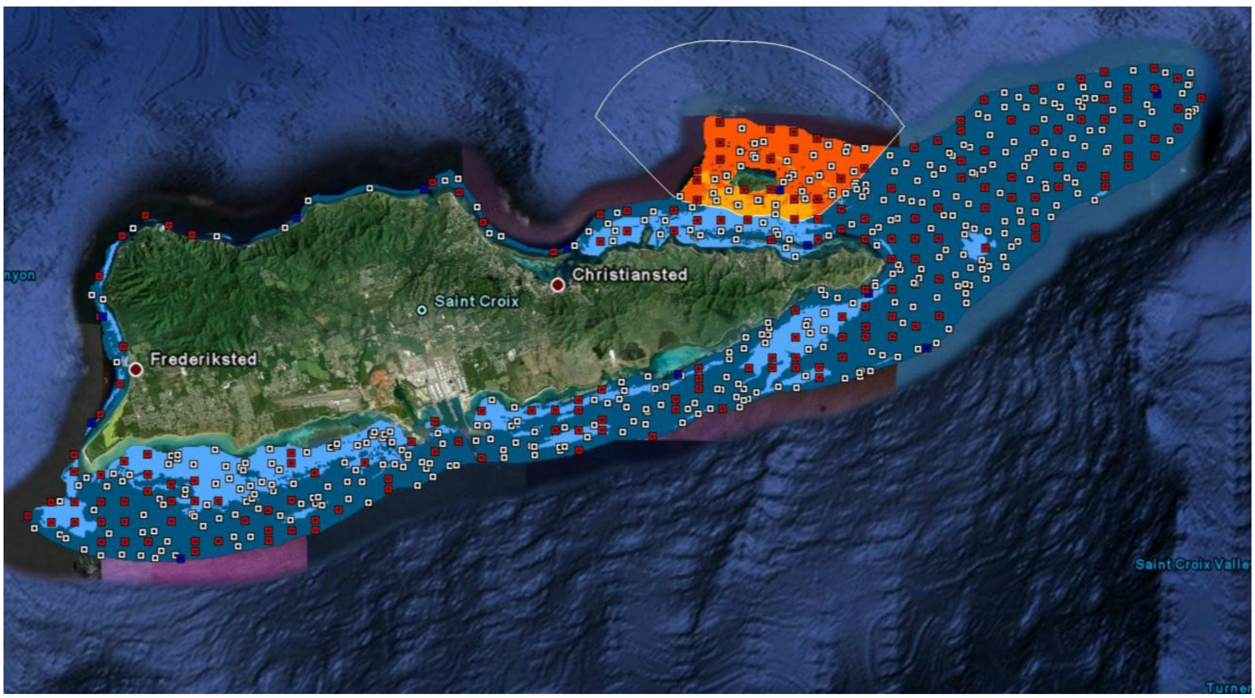


Figure 1. A map of the sampling locations around St. Croix. The color indicates the allocation strategy: SRD (white; n=400), SOD (red; n = 200), and fixed stations (blue; n = 14).

*Cooperative implementation*

Collaborating with the fishing community was an important goal of this project to ensure transparency, communication, and partnership. Ten St. Croix fishers actively participated in this study by using and captaining their own vessels, developing gear and fishing procedures, and hauling and setting the gear. Each vessel fished using chevron traps (4 feet long, 5 feet wide, and 1.5 feet high) designed by the fishers and baited with squid (Figure 2). The fish traps were deployed at the pre-determined sampling sites. The experimental design included 24 hour soak times for each trap, but given field logistics, soak times ranged from 16 hours to 48 hours. Scientific observers from St. Croix helped the fishers set and collect the traps and survey data. On-board observers noted the trap set and haul time and location, sea conditions, depth, catch (to species), and fork length of each captured fish. They also ensured that fish were released properly and in areas where trap contents had to be released.

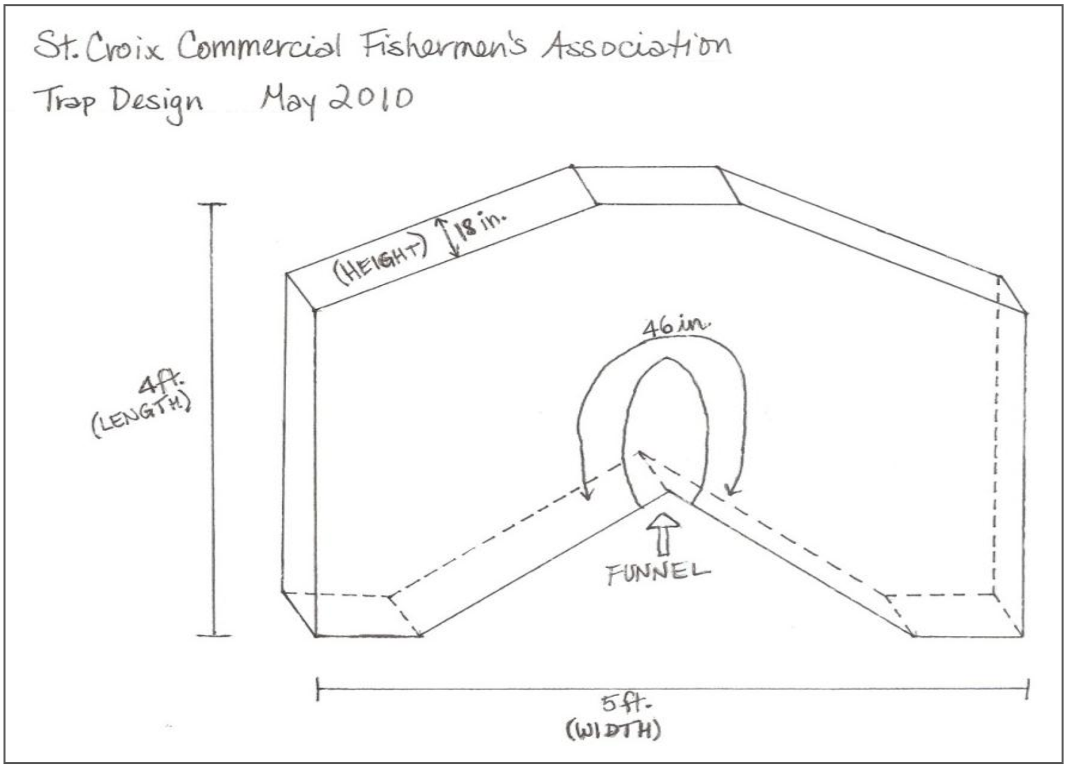


Figure 2. Hand drawing of chevron trap design developed collaboratively by fishers and scientists.

Photo 1. Commercial fisher Tom Daley prepares the meal of potfish (top left) and commercial fishers and scientific personnel building fish traps.

*Project Execution*

Sampling took place over 29 days between October 5 and November 13, 2010 at a total of 638 sites. More traps were set and sampled than originally planned due to trap misplacement. Fishers generally captained their own boats and hosted a project observer to collect the survey data. Fishers generally set or hauled 30 traps per day with allowances for sea conditions, equipment and supplies, and distance from shore. Table 1 summarizes daily trap haul and set effort.

## Results

Figure 3 illustrates the total number of fish caught per trap at all survey locations. A total of 2,860 individual fish were caught and measured, including over 50 species. A list of all species captured during the survey and the numbers caught is included in Appendix B.

Table 1.  Number of traps set and hauled each day.

| Date | # Set | # Hauled | Date | # Set | # Hauled |
|---|---|---|---|---|---|
| 10/5/2010 | 30 | 0 | 10/22/2010 | 30 | 30 |
| 10/6/2010 | 22 | 22 | 10/23/2010 | 0 | 30 |
| 10/8/2010 | 25 | 28 | 10/27/2010 | 2 | 0 |
| 10/9/2010 | 29 | 26 | 10/28/2010 | 0 | 2 |
| 10/10/2010 | 30 | 30 | 10/29/2010 | 12 | 0 |
| 10/11/2010 | 30 | 30 | 10/30/2010 | 0 | 12 |
| 10/12/2010 | 30 | 30 | 11/1/2010 | 12 | 0 |
| 10/13/2010 | 30 | 30 | 11/2/2010 | 14 | 12 |
| 10/14/2010 | 30 | 30 | 11/3/2010 | 14 | 14 |
| 10/15/2010 | 30 | 30 | 11/4/2010 | 15 | 14 |
| 10/16/2010 | 30 | 30 | 11/5/2010 | 0 | 15 |
| 10/17/2010 | 30 | 30 | 11/10/2010 | 29 | 0 |
| 10/18/2010 | 30 | 30 | 11/11/2010 | 30 | 29 |
| 10/19/2010 | 30 | 30 | 11/12/2010 | 14 | 30 |
| 10/20/2010 | 30 | 30 | 11/13/2010 | 0 | 14 |
| 10/21/2010 | 30 | 30 | | | |

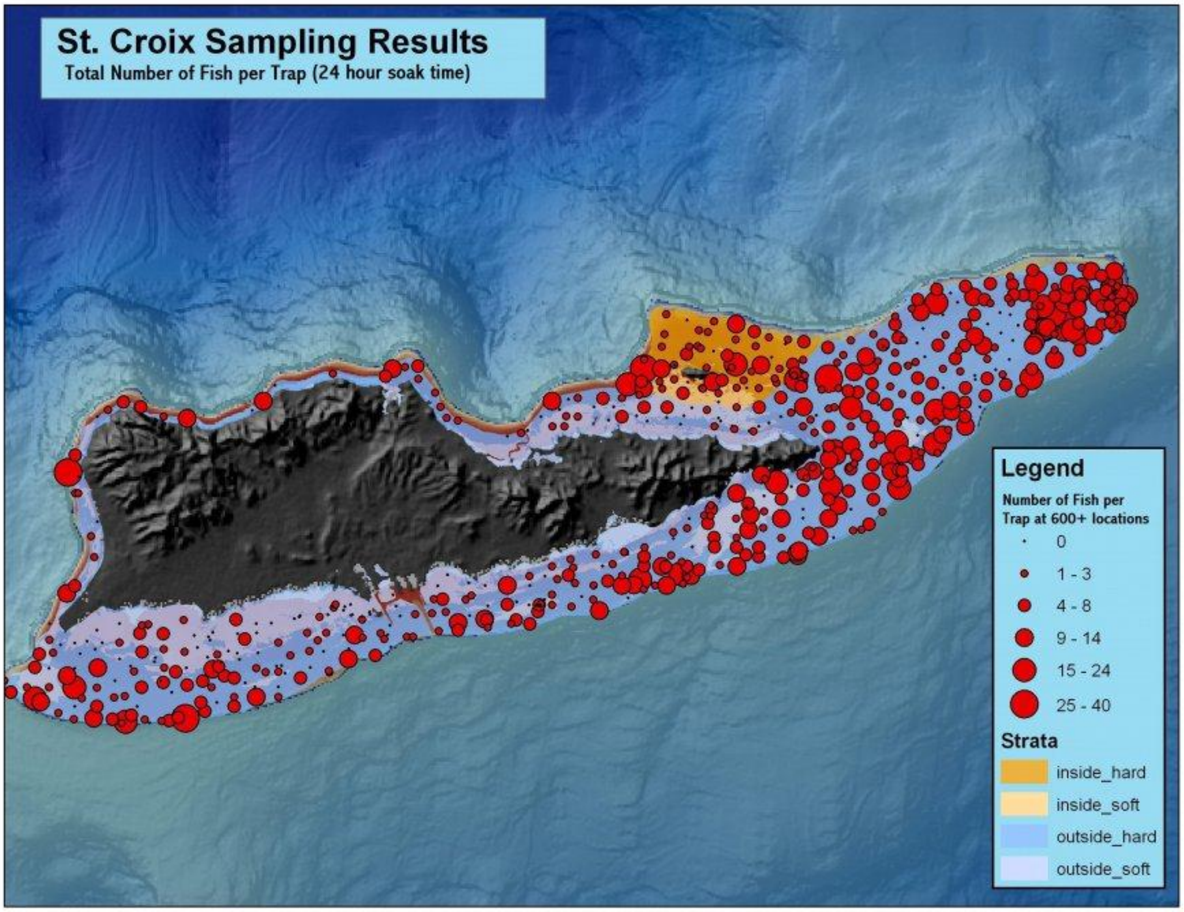


Figure 3. Map indicating the number of fish caught per trap in survey locations around St. Croix.

Tables 2-5 summarize data associated from the SRD and SOD by habitat type. A total of 217 stations were excluded from this analysis. These stations were removed because they either were placed in locations not according to the experimental design, haul locations were greater than 152 meters from the set location, or were associated with fixed station locations. A total of 280 stations from the SRD and 141 stations from the SOD were used in this analysis.

The mean catch per trap, the number of captured species, and the mean number of captured species were greater in hard-bottom habitats than in soft-bottom habitats both within and outside of BIRNM for stations associated with the SRD (Table 2). The standard deviations associated with mean catch per trap were large and overlapped indicating wide variability in catch rates (Table 2). A Wilcoxon ranks-sum test indicated that mean catch per trap was significantly higher in hard-bottom habitats than in soft-bottom habitats (p=0.02). Among the categorized habitat types, mean catch per trap was generally highest in coral patches, linear reef, patch reefs, and macroalgae (Table 3).

Overall, mean catch per trap was higher in hard-bottom than soft-bottom habitats for stations associated with the SOD (Table 4). A Wilcoxon ranks-sum test indicated that this difference was significant (p=0.01). A comparison of the two habitat types inside and outside of BIRNM indicated that mean catch per trap was greater in hard-bottom than soft-bottom habitats outside of BIRNM, whereas mean catch per trap was greater in soft-bottom than hard-bottom habitats found in BIRNM (Table 4). This interaction can be described by greater mean catch per trap in seagrass inside BIRNM and greater mean catch per trap in coral patches and linear reef habitat outside of BIRNM (Table 5). It should be noted that comparisons between observations from inside and outside of BIRNM should be interpreted cautiously due to an NPS requirement to relocate the placement of SRD stations within BIRNM (see Appendix A for more details). The number of species captured was greater in hard-bottom than soft-bottom habitats and the mean number of species captured per trap was similar between the two habitat types (Table 4).

Table 2. The number of stations (samples), the total number of individuals and unique species, the mean number of individuals and species per trap, and the standard deviations per location and bottom type from SRD Survey. Location is the sampling location inside or outside of Buck Island Reef National Monument and the combination of the two (Both). * Direct comparisons between inside and outside BIRNM cannot be made due to changes in trap locations not in accordance with the SRD.

| Location | Bottom type | # of samples | Catch (numbers) | Mean catch (numbers) per trap | Standard deviation | # Species | Mean # species | Standard deviation |
|---|---|---|---|---|---|---|---|---|
| Inside* | Hard-bottom | 21 | 106 | 5.05 | 5.24 | 18 | 2.76 | 2.07 |
| | Soft-bottom | 7 | 17 | 2.43 | 2.57 | 7 | 1.14 | 0.38 |
| Outside | Hard-bottom | 219 | 1347 | 6.15 | 5.51 | 44 | 2.82 | 1.73 |
| | Soft-bottom | 33 | 131 | 3.97 | 2.99 | 18 | 1.76 | 0.87 |
| Both | Hard-bottom | 240 | 1453 | 6.05 | 5.48 | 44 | 2.81 | 1.75 |
| | Soft-bottom | 40 | 148 | 3.70 | 2.95 | 20 | 1.65 | 0.83 |

Table 3. The number of stations (samples), the total number of individuals and unique species, the mean number of individuals and species per trap, and the standard deviations per location and habitat type from SRD survey. Location is the sampling location inside or outside of Buck Island Reef National Monument and the combination of the two (Both). CP - colonized pavement, PR- patch reef, SC - scattered coral, and US - unconsolidated sediment. * Direct comparisons between inside and outside cannot be made due to movement of sampling locations not in accordance with the stratified random design.

| Location | Habitat type | # of samples | Catch (numbers) | Mean catch (numbers) per trap | Standard deviation | # Species | Mean # species | Standard deviation |
|---|---|---|---|---|---|---|---|---|
| Inside* | CP | 6 | 26 | 4.33 | 5.85 | 6 | 1.83 | 1.33 |
| | CP with Sand Channels | 5 | 26 | 5.20 | 3.83 | 10 | 3.40 | 2.30 |
| | PR (Aggregated) | 7 | 40 | 5.71 | 6.70 | 12 | 3.14 | 2.54 |
| | Sand | 2 | 2 | 1.00 | 0.00 | 2 | 1.00 | 0.00 |
| | SC/Rock in US | 3 | 14 | 4.67 | 4.62 | 6 | 2.67 | 2.08 |
| | Seagrass | 5 | 15 | 3.00 | 2.92 | 5 | 1.20 | 0.45 |
| Outside | CP | 76 | 488 | 6.42 | 5.24 | 33 | 2.70 | 1.74 |
| | CP with Sand Channels | 102 | 622 | 6.10 | 4.99 | 34 | 3.07 | 1.72 |
| | Linear Reef | 14 | 95 | 6.79 | 9.85 | 13 | 2.07 | 0.92 |
| | Macroalgae | 12 | 64 | 5.33 | 3.14 | 12 | 2.00 | 0.95 |
| | PR (Aggregated) | 11 | 79 | 7.18 | 6.95 | 12 | 3.09 | 2.07 |
| | Sand | 2 | 7 | 3.50 | 3.54 | 4 | 2.00 | 1.41 |
| | SC/Rock in US | 16 | 63 | 3.94 | 3.68 | 15 | 2.25 | 1.73 |
| | Seagrass | 19 | 60 | 3.16 | 2.69 | 12 | 1.58 | 0.77 |
| Both | CP | 82 | 514 | 6.27 | 5.27 | 33 | 2.63 | 1.72 |
| | CP with Sand Channels | 107 | 648 | 6.06 | 4.93 | 34 | 3.08 | 1.74 |
| | Linear Reef | 14 | 95 | 6.79 | 9.85 | 13 | 2.07 | 0.92 |
| | Macroalgae | 12 | 64 | 5.33 | 3.14 | 12 | 2.00 | 0.95 |
| | PR (Aggregated) | 18 | 119 | 6.61 | 6.70 | 16 | 3.11 | 2.19 |
| | Sand | 4 | 9 | 2.25 | 2.50 | 6 | 1.50 | 1.00 |
| | SC/Rock in US Sediment | 19 | 69 | 3.63 | 3.30 | 16 | 2.11 | 1.33 |
| | Seagrass | 24 | 75 | 3.13 | 2.68 | 15 | 1.50 | 0.72 |

Table 4. The number of stations (samples), the total number of individuals and unique species, the mean number of individuals and species per trap, and the standard deviations per location and habitat type from SOD survey. Location is the sampling location inside or outside of Buck Island Reef National Monument and the combination of the two (Both). * Direct comparisons between inside and outside cannot be made due to movement of sampling locations not in accordance with the stratified random design.

| Location | Bottom type | # of samples | Catch (numbers) | Mean catch (numbers) per trap | Standard deviation | # Species | Mean # species | Standard deviation |
|---|---|---|---|---|---|---|---|---|
| Inside* | Hard-bottom | 11 | 40 | 3.64 | 4.13 | 10 | 2.27 | 1.62 |
| | Soft-bottom | 4 | 31 | 7.75 | 12.18 | 8 | 2.00 | 1.41 |
| Outside | Hard-bottom | 110 | 664 | 6.04 | 4.77 | 43 | 2.94 | 1.61 |
| | Soft-bottom | 16 | 47 | 2.94 | 1.91 | 13 | 1.63 | 0.96 |
| Both | Hard-bottom | 121 | 704 | 5.82 | 4.75 | 44 | 2.88 | 1.62 |
| | Soft-bottom | 20 | 78 | 3.90 | 5.50 | 16 | 1.70 | 1.03 |


Photo 2. Fishers setting and hauling fish traps as part of this cooperative fishery-independent trap survey.

Table 5. The number of stations (samples), the total number of individuals and unique species, the mean number of individuals and species per trap, and the standard deviations per location and habitat type. Location is the sampling location inside or outside of Buck Island Reef National Monument and the combination of the two (Both). The summarized observations are from sampling locations chosen as part of a model based selection procedure finding spatially optimal sampling locations. CP - colonized pavement, PR- patch reef, SC - scattered coral, and US - unconsolidated sediment. * Direct comparisons between inside and outside cannot be made due to movement of sampling locations not in accordance with the stratified random design.

| Location | Habitat type | # of samples | Catch (numbers) | Mean catch (numbers) per trap | Standard deviation | # of species | Mean # of species | Standard deviation |
|---|---|---|---|---|---|---|---|---|
| Inside* | CP | 6 | 32 | 5.33 | 5.09 | 8 | 3.00 | 1.90 |
| | CP with Sand Channels | 4 | 5 | 1.25 | 0.50 | 3 | 1.25 | 0.50 |
| | PR (Aggregated) | 1 | 3 | 3.00 | - | 2 | 2.00 | - |
| | Sand | 1 | 2 | 2.00 | - | 1 | 1.00 | - |
| | Seagrass | 3 | 29 | 9.67 | 14.15 | 7 | 2.33 | 1.53 |
| Outside | CP | 41 | 253 | 6.17 | 4.59 | 33 | 3.00 | 1.73 |
| | CP with Sand Channels | 55 | 356 | 6.47 | 5.25 | 31 | 3.02 | 1.57 |
| | Linear Reef | 2 | 8 | 4.00 | 1.41 | 4 | 2.00 | 0.00 |
| | Macroalgae | 4 | 13 | 3.25 | 1.50 | 3 | 1.50 | 0.58 |
| | PR (Aggregated) | 2 | 6 | 3.00 | 1.41 | 4 | 2.00 | 0.00 |
| | Sand | 6 | 20 | 3.33 | 1.86 | 9 | 2.17 | 1.33 |
| | SC/Rock in US | 10 | 41 | 4.10 | 2.85 | 16 | 2.60 | 1.65 |
| | Seagrass | 6 | 14 | 2.33 | 2.34 | 5 | 1.17 | 0.41 |
| Both | CP | 47 | 285 | 6.06 | 4.60 | 34 | 3.00 | 1.73 |
| | CP with Sand Channels | 59 | 361 | 6.12 | 5.23 | 32 | 2.90 | 1.58 |
| | Linear Reef | 2 | 8 | 4.00 | 1.41 | 4 | 2.00 | 0.00 |
| | Macroalgae | 4 | 13 | 3.25 | 1.50 | 3 | 1.50 | 0.58 |
| | PR (Aggregated) | 3 | 9 | 3.00 | 1.00 | 6 | 2.00 | 0.00 |
| | Sand | 7 | 22 | 3.14 | 1.77 | 10 | 2.00 | 1.29 |
| | SC/Rock in US | 10 | 41 | 4.10 | 2.85 | 16 | 2.60 | 1.65 |
| | Seagrass | 9 | 43 | 4.78 | 8.18 | 9 | 1.56 | 1.01 |

*Soak time*

While the sampling protocol called for a 24 hour soak time for each trap, weather and logistics caused trap soak times to very between 16 and 48 hours. An exploratory analysis was conducted to evaluate if the variability in soak times resulted in distinct differences in catch. Figures 4 and 5 summarize the catch data for the stations associated with the SRD and the SOD. While an increasing pattern from the lowest soak times to approximately 23 hours was observed for the aggregate catch, patterns in catch per trap across the range of soak time were not obvious. Thus, analysts decided to present raw, non-standardized, values in the summaries. Gear saturation, which is a function of soak time, can cause dis-proportionality between catch rates and abundance (Hilborn and Walters 1992). Future studies should investigate the effects of soak time on the catch rates of commonly caught species in the US Caribbean to determine if this is an important factor biasing catch rates.

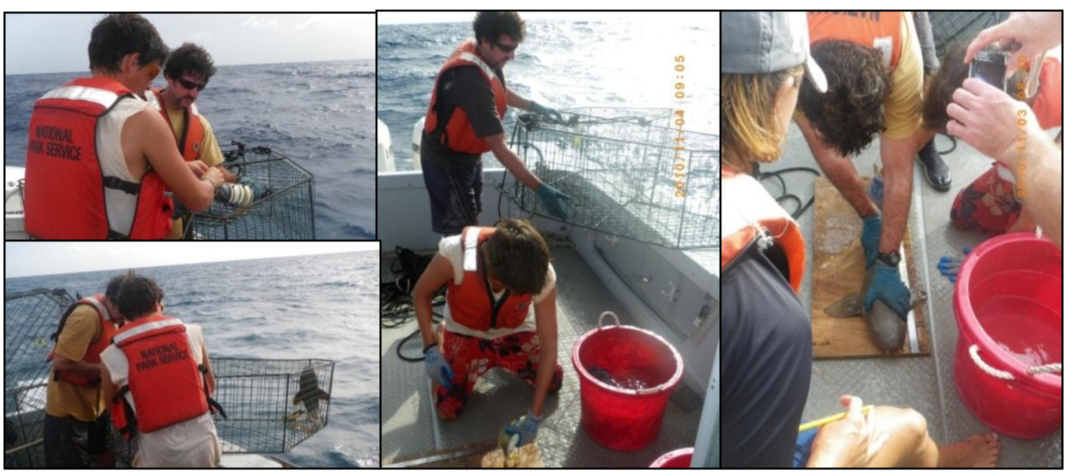


Photo 3. Sampling in Buck Island Reef National Monument as part of this survey.

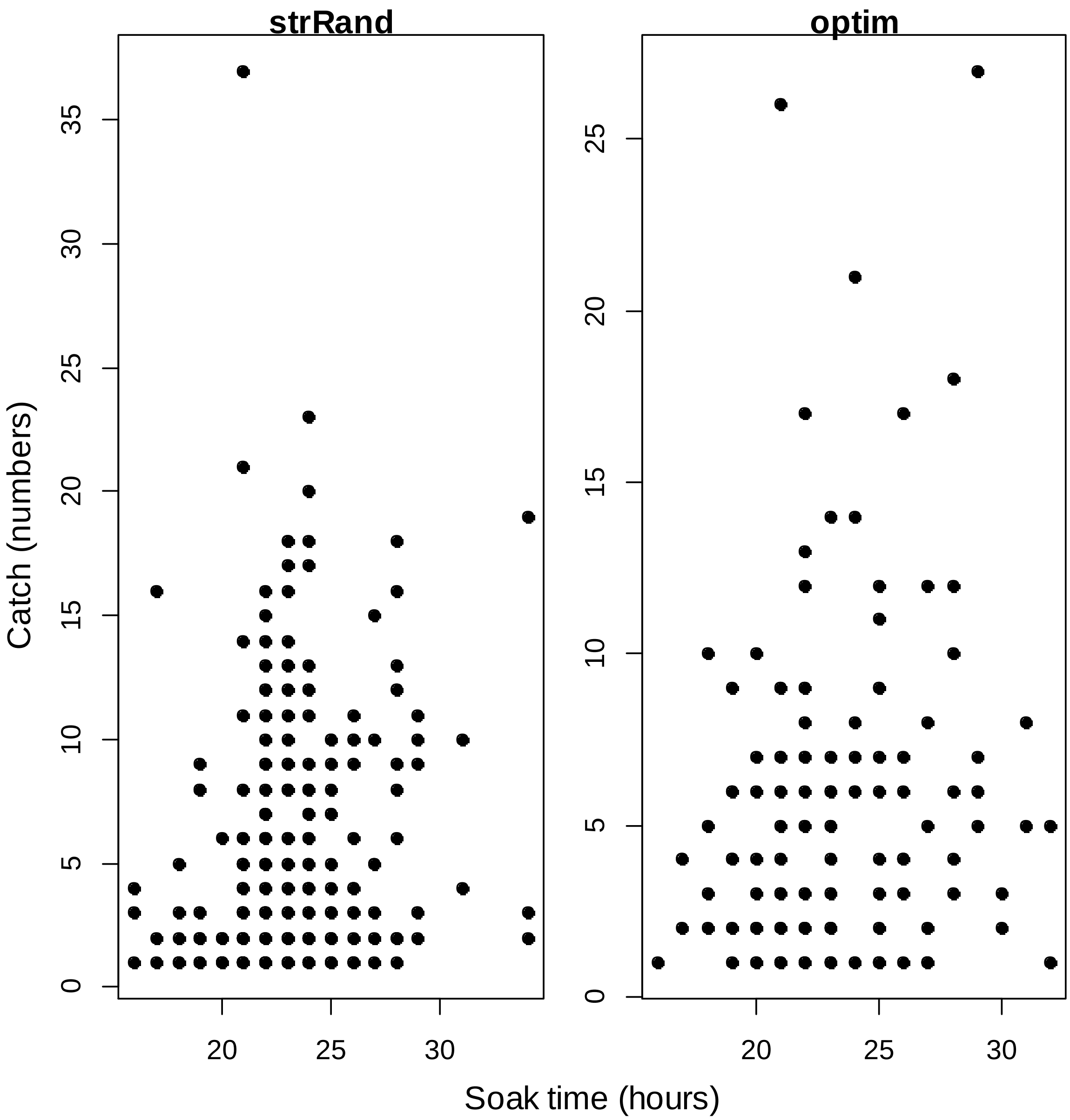


Figure 4. Catch (number of fish) per trap across the range of soak time (hours) for those stations associated with SRD (left panel) and SOD (right panel).

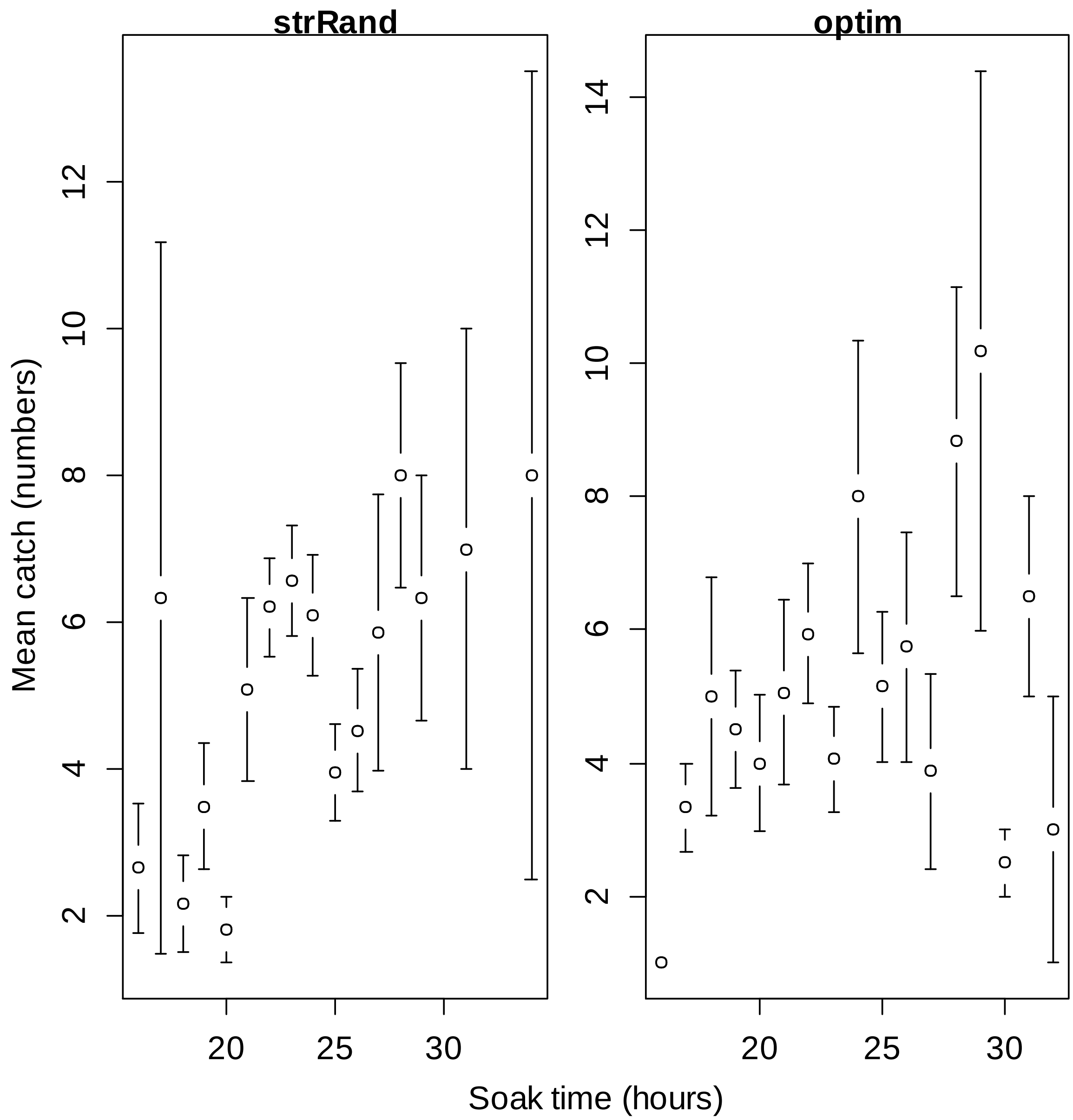


Figure 5. Mean catch per trap (number of fish, shown as open circles) and the associated standard error (vertical bars) across the range of soak time for stations associated with SRD (left panel) and SOD (right panel).

*Depth*

Sampling locations varied in depth from ~3 - 57 meters. and Figures 8 and 9 summarize the data for the SRD and SOD locations, respectively. The mean catch per trap was variable across depth for stations associated with the SRD and the SOD. The highest mean catch per trap associated with the SRD was in 51.5 m of water and caught by a single trap (Figure 8). Excluding this outlier, mean catch per trap was generally highest between 14.9 m and 60.66 m (Figure 8). Mean catch per trap for those stations associated with the SOD was generally highest between 7.62 m and 32 m (Figure 9). As analysts move forward to standardize catch rates for individual species the effect of depth will likely be influential on a species by species basis and should be considered in index standardization procedures.

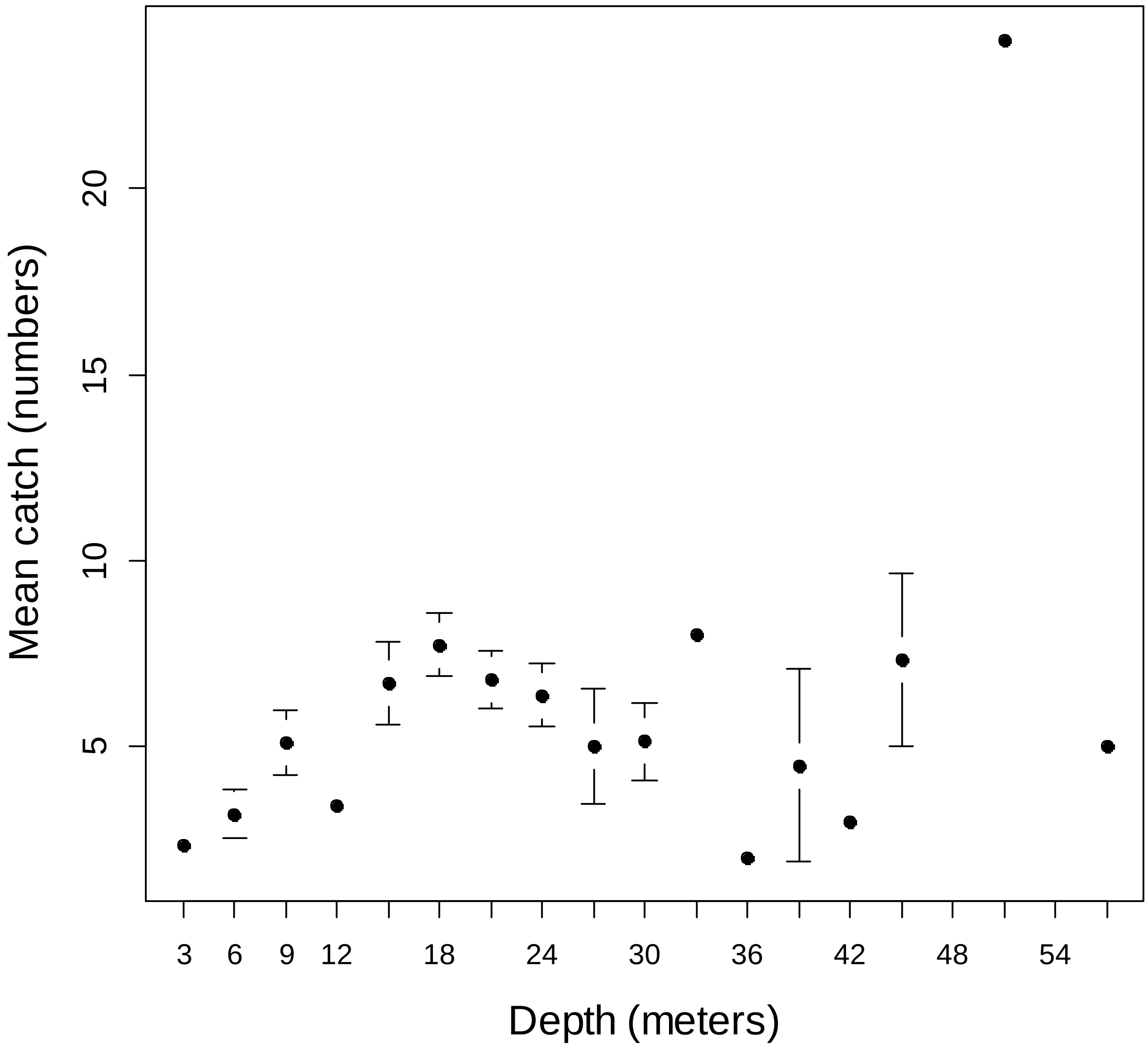


Figure 8. Mean catch per trap (± SE) with respect to depth for the SRD sampling stations. Depth categories on the x-axis are labeled by the minimum depth of each category. Depth categories are in 3 meter increments based on the maximum and minimum observed depths.

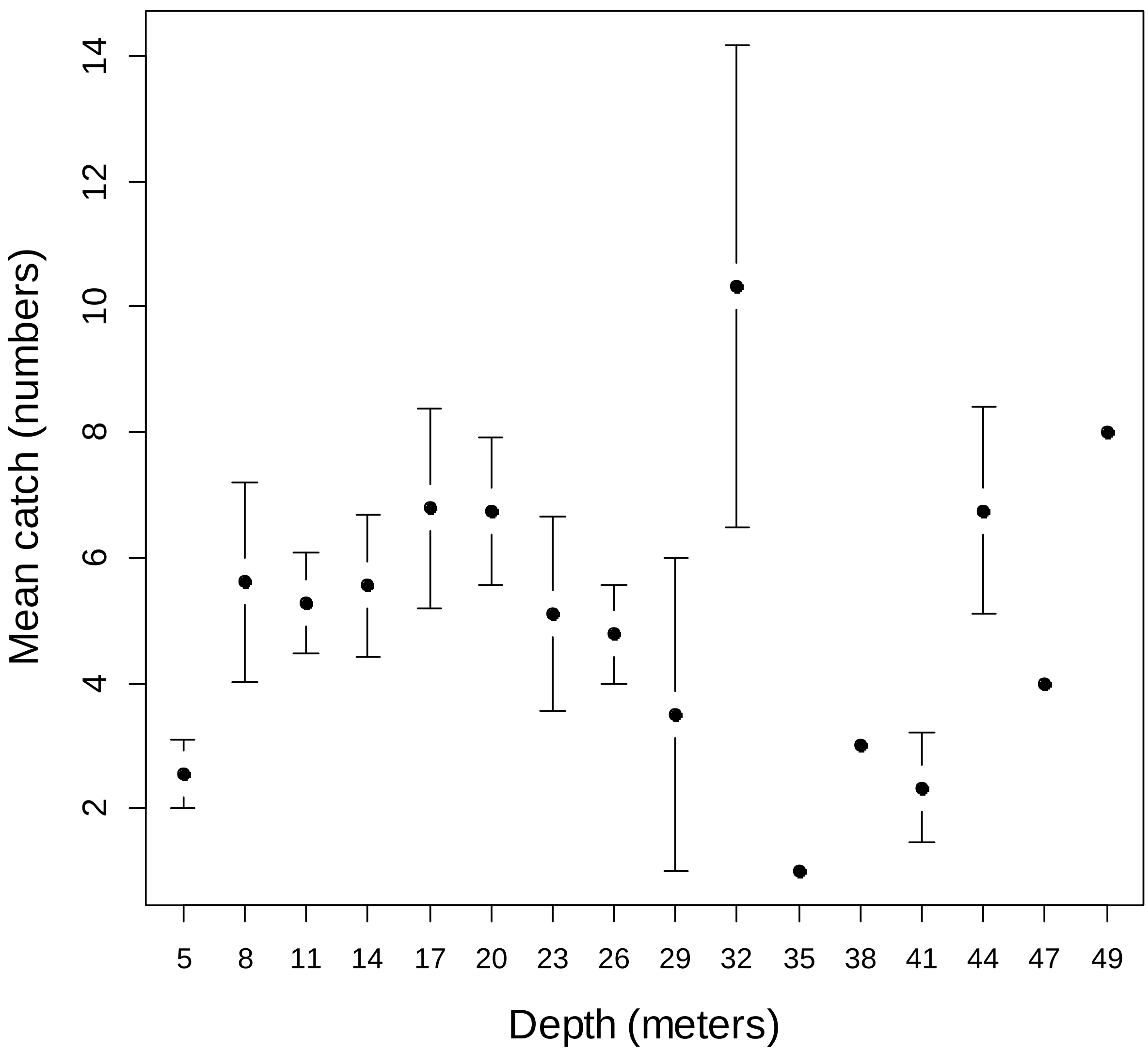


Figure 9. Mean catch per trap (± SE) with respect to depth for the SOD sampling stations. Depth categories on the x-axis are labeled by the minimum depth of each category. Depth categories are in 3 meter increments based on the maximum and minimum observed depths.

## Conclusions

This report provides a brief summary of the collaborative St. Croix fishery-independent trap study. Overall, the project was a success and we were able to demonstrate that working directly with the local fishing community can yield results in a cost effective manner.

For the first time in the US Caribbean, we have a spatially comprehensive, fishery-independent survey of species-specific catch and the length-frequency of the catch. Future explorations of this database should include a comparison of the length structure derived from this work and the length-frequency data collected through the Trip Interview Program (TIP, fishery-dependent port sampling). This will allow for the validation of the fishery dependent information, leading to stronger assessment conclusions.

This study was designed to over-sample the St. Croix shelf. Moving forward, the data should be evaluated to determine the optimal number of sampling locations and spatial coverage required to achieve a certain level of precision in the catch rate data derived from this type of study. This is will be an important analysis to conduct, so that the results can be used to guide future fishery-independent surveys in St. Croix and the US Caribbean.

## Acknowledgements

We would like to extend a very special thank you to the commercial fishers of St. Croix. In particular, we would like to thank Tom Daley, Gerson Martinez, and Eddie Schuster. Without their ongoing support and commitment, this project could not have been completed. Additionally, their knowledge stemming from years of experience fishing in St. Croix's waters greatly assisted in the development of the survey design and sampling strategy. Both Tom and Gerson allowed trap supplies and frozen bait to be stored at their homes for several months free of charge, and were always available and willing to donate their time and energy to ensure all tasks were completed. We would also like to thank all the other licensed commercial fishers and fisher helpers who participated in this project: Manuel Mercado and his helper Brady, Homer Kelly and his helper Charlie, Norris Benjamin and his helper Gilles, Sylvester, and Salvador Martinez.

We would like to thank Eddie Schuster (President) and Gerson Martinez (Vice President) for offering the support of the St. Croix Commercial Fishermen's Association. They were critical to gathering support for the project among the commercial fishing community, and for helping to recruit additional fishers to participate.

We also owe the success of the project to Carlos Farchette (Caribbean Fisheries Management Council). Carlos played a crucial role in helping to motivate both commercial fishers and scientific personnel to persist in the survey efforts even when things became quite challenging.

We would also like to thank Liam Carr and Sandy Schexnayder for the integral role they played as scientific observers. The survey would not have been completed without their hard work and perseverance.

We would also like to thank several of the DPNR staff, including Jed Brown, William Tobias, Willy Ventura, Hector Rivera, and Howard Forbes, who offered their support for the project. Additionally, Willy and Hector helped train scientific observers in fish identification, and allowed trainees to accompany them when conducting port samples.

We also would like to thank National Park Service staff Joel Tutein, Zandy Hillis-Starr, and Ian Lundgren for allowing the continuation of the survey inside the monument boundaries even in the temporary absence of the drop camera. A very special thank you to Tyler Smith and others from the University of the Virgin Islands for quickly shipping a replacement drop camera to us and allowing us to use it for the remainder of our fieldwork inside the monument.

Additionally, we would like to thank Caribbean Printing and Marketing for printing the project data sheets at a reduced cost, and to Ross McCaskey for providing the trap plan drawings.

Lastly, we would like to thank Jennifer Schull (NOAA Fisheries, Southeast Science Center) who was instrumental in the development and implementation of this project.

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## APPENDIX A – Sampling Design

*Delineation of Sampling Frame and allocation of Stratified Random Stations*

The sampling design used in this project is an innovative approach that combines both a classic stratified random design with a systematic (i.e. model based) optimal allocation strategy. Initially, a stratified random sampling approach with stratification based upon habitat type (i.e., hard-bottom and soft-bottom habitats) was employed on the fishable shelf of St. Croix, USVI. Certain criteria were selected a priori to establish a 'sampling mask' and to exclude specific known features (i.e. sensitive habitats) and contain sampling effort within a defined depth range. First, the GeoDas 90 meter resolution bathymetric dataset was used to create a shapefile around St. Croix that encompassed the 3-55 meter depth range. Secondly, the NOAA benthic habitat map was overlaid and classed into hard-bottom and soft-bottom categories. We then used an ArcGis point file containing all known locations of *Acropora* species within the specified depth range, added a 10 meter buffer zone around the points, and then removed those from the habitat shapefile so that no random samples could fall on those sensitive areas. Using a 2007 digital orthophotogragh of St. Croix (0.3 meter resolution), a hand digitized shapefile was created of all shallow barrier reef features that were originally included in the habitat map and depth range shapefile. This emerging reef shapefile was used to exclude those features from the habitat shapefile so no random points could fall on coral reefs < 3m (9 ft). Finally, the Buck Island Reef National Monument closure was overlaid and used to delineate the boundary and define sampling strata. The final sampling domain consisted of all the St. Croix shelf between 2.74 and 53.64 meters depth that were included in the NOAA benthic habitat map, excluding shallow emerging reefs and known locations of *Acropora* species.

The final sampling mask was then categorized into four strata as part of the stratified random protocol and included; 1) hard-bottom habitat outside the BIRNM, 2) soft-bottom habitat outside the BIRNM, 3) hard-bottom habitat inside the BIRNM and 4) soft-bottom habitat inside the BIRNM. Using ArcGis, the total area of each stratum was determined and used to weight the number of random samples in each stratum. A total of 400 area-weighted random locations were determined using Hawth's tools inside ArcGis and the augmented SOD sample selection tool described below.

*Allocation of Sampling Stations Based on Spatially Optimal Design*

The method described above gives an unbiased (in expectation) estimate of an index for overall fish abundance but does not necessarily ensure complete spatial coverage or provide information in local areas necessary for a comprehensive mapping. To fill in the spatial gaps we developed a geostatistical sample allocation scheme that adds samples to minimize the total spatial variance, called a “spatially optimal design” (SOD) throughout this document. Geostatistical methods provide a means of using spatial autocorrelation to predict both spatial abundances but also associated prediction error. Geostatistical prediction uses the property of spatial autocorrelation, where close objects are more alike than those further apart. The method uses a statistical measure of this autocorrelation called a variogram to quantify the strength and shape of the spatial correlation. Geostatistical sample allocation uses the initial set of stratified random points to obtain the geostatistical prediction variance for the entire area and then identifies the location that minimizes the total prediction error. Then the prediction variance is recalculated, assuming that this sample had been added and a new location is chosen, and so on. This iteratively adds samples to fill in gaps in spatial information, each time choosing the most optimal location to minimize the overall spatial variance. The benefit of this approach is that it can be done *a priori* without the samples actually having been taken because the prediction variance is solely a function of sample spacing and pattern of spatial autocorrelation. The single additional requirement is that we have prior knowledge about the variogram, which describes the spatial auto-correlation between geographic variables. The variogram used in this study was borrowed from analyses of spatial autocorrelation of reef fish visual survey data in the Gulf of Mexico and used a range of autocorrelation of 1 kilometer.  Project PIs added a total of 187 additional sampling locations using both known fixed visual census sites and the geostatistical sample allocation method to augment the stratified-random approach for a sum total of 638 sampling sites.

It is important to note that the station locations presented in Figure 1 were the designed locations and some were moved prior to sampling (see below).  The stations chosen by the geostatistical sample allocation method were determined based on the locations of the stations originally chosen by the stratified random design and the location of critical habitats.  The geostatistical sampling allocation can only provide final locations once all other known stations are selected.

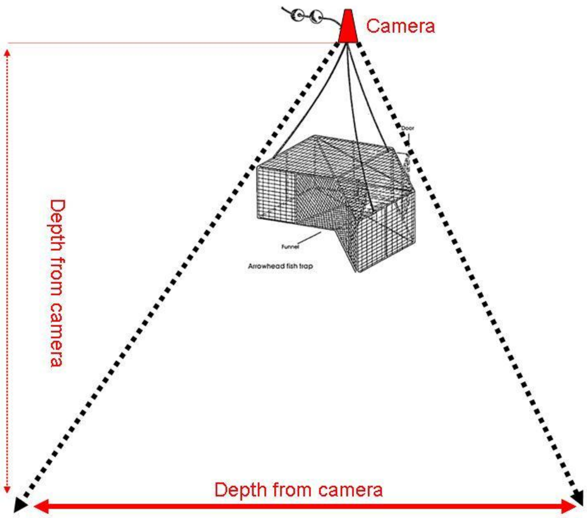
*Modifications Necessary for Sampling in Buck Island Reef National Monument (BIRNM)*

BIRNM resource managers required a number of modifications to the original survey design and protocols after the project was underway to provide additional safeguards of sensitive marine habitats, especially federally threatened *Acropora* corals.

An inverse distance weighting (IDW) interpolation file (based on Mayor et al. 2006 and the same points used in the original protocols) was used to define critical habitat that warranted additional sampling requirement.  From the IDW file, any location with a positive value (i.e. > 0.0002) was included.  The following procedures were then implemented:

a) All sites within the BIRNM, and outside the IDW area warranted additional procedures. A Seaviewer drop camera was placed just above the bridle on the trap.  A surface monitor allowed real-time viewing and careful placement of the trap.  The lens viewing angle is a 1:1 relationship so at 14.9 meters off the bottom a corresponding area of 14.9 meters was in view.   The trap and camera were slowly lowered to grossly evaluate the widest swath of habitat given water visibility.  A small circle around the sampling location was conducted to insure that necessary buffers in (b) below are met. Once the broader area had been verified to meet buffer requirements, the trap was slowly lowered until it contacts the bottom. Real-time video monitoring of the entire placement insured smaller features were identified as close-up/high resolution images become available with decreasing distance from bottom. The camera was pulled back up the trap line insuring no movement had occurred and safe haulback could be achieved. Recordings/images were captured at each site if possible.

Figure C2: Viewing Range of Seaviewer Camera




b) In locations where ‘massive, high relief, or branching hard corals’ were present, the following buffers were used and traps were placed a minimum distance from said corals of: 2.98 meters in depths below 9.1 meters; 7.92 meters in depths between 9.1 and 18.3 meters; and 9.99 meters in depths greater than 18.3 meters.

c) Additional care was taken to ‘avoid tall sponges and gorgonians’ when possible.

d) A BIRNM vessel was utilized for all work in the park. Given logistical constraints, an additional vessel could have been used with at least 24 hours for approval. Hank Tonnemacher (co-PI) was the only captain permitted to oversee scientific operations on any vessel deploying traps within BIRNM.

e) Traps were only deployed in good weather when minimal groundswell is present and conditions were suitable to minimize the potential for trap movement. The PI’s used rebar for extra weighting in trap construction so movement of any kind was not expected.

f) All original sampling locations were moved to the nearest locations that fell outside of the IDW interpolated area (~300 meters in one case). Ideally to remain consistent with overall St. Croix sampling design and provide a complete picture of resources within BIRNM, the PI's would have preferred to sample locations throughout the park and within the IDW "masked –out" area. The PI's requested reconsideration of this requirement if logistics could be arranged (e.g. the NOAA Biogeography team will be contacted to see if a coordinated effort can be arranged) and divers would be used to place traps by hand in the IDW region according to the buffers in (b) above. BIRNM resource managers would be notified for prior approval.

Mayor, P.A., Rogers, C.S., Hillis-Starr, Z.M. 2006. Distribution and abundance of elkhorn coral, *Acropora palmate*, and prevalence of white-band disease at Buck Island Reef National Monument, St. Croix, US Virgin Islands. Coral Reefs 25: 239-242.

## APPENDIX B. Species summary

Table B1. Full list of species caught during the survey.

| Species | Scientific name | Number captured | Percent of total | Total catch |
|---|---|---|---|---|
| White Grunt | *Haemulon plumieri* | 623 | 21.78 | 2860 |
| Queen Triggerfish | *Balistes vetula* | 371 | 12.97 | |
| Blue Tang | *Acanthurus coeruleus* | 298 | 10.42 | |
| Banded Butterflyfish | *Chaetodon striatus* | 218 | 7.62 | |
| Yellowtail Snapper | *Ocyurus chrysurus* | 196 | 6.85 | |
| Doctorfish | *Acanthurus chirurgus* | 166 | 5.80 | |
| Black Durgon | *Melichthys niger* | 152 | 5.31 | |
| Schoolmaster | *Lutjanus apodus* | 122 | 4.27 | |
| Red Hind | *Epinephelus guttatus* | 111 | 3.88 | |
| Blue Runner | *Caranx crysos* | 85 | 2.97 | |
| Ocean Surgeonfish | *Acanthurus bahianus* | 62 | 2.17 | |
| Nurse Shark | *Ginglymostoma cirratum* | 38 | 1.33 | |
| Spotfin Butterflyfish | *Chaetodon ocellatus* | 37 | 1.29 | |
| Scrawled Filefish | *Aluterus scriptus* | 32 | 1.12 | |
| Bluestriped Grunt | *Haemulon sciurus* | 28 | 0.98 | |
| Smooth Trunkfish | *Rhinesomus triqueter* | 26 | 0.91 | |
| Caesar Grunt | *Haemulon carbonarium* | 24 | 0.84 | |
| Lane Snapper | *Lutjanus synagris* | 23 | 0.80 | |
| Scrawled Cowfish | *Acanthostracion quadricornis* | 22 | 0.77 | |
| Bar Jack | *Caranx ruber* | 19 | 0.66 | |
| Cottonwick | *Haemulon melanurum* | 15 | 0.52 | |
| Foureye Butterflyfish | *Chaetodon capistratus* | 15 | 0.52 | |
| Spotted Trunkfish | *Lactophrys bicaudalis* | 15 | 0.52 | |
| Coney | *Cephalopholis fulva* | 14 | 0.49 | |
| Caribbean Spiny Lobster | *Panulirus argus* | 12 | 0.42 | |
| Honeycomb Cowfish | *Acanthostracion polygonius* | 12 | 0.42 | |
| Mutton Snapper | *Lutjanus analis* | 11 | 0.38 | |
| Squirrelfish | *Holocentrus adscensionis* | 11 | 0.38 | |
| Green Moray Eel | *Gymnothorax funebris* | 9 | 0.31 | |
| Queen Angelfish | *Holacanthus ciliaris* | 9 | 0.31 | |
| Bermuda Chub | *Kyphosus sectatrix* | 7 | 0.24 | |
| Chub | *Kyphosus incisor* | 7 | 0.24 | |
| French Angelfish | *Pomacanthus paru* | 6 | 0.21 | |
| Nassau Grouper | *Epinephelus striatus* | 5 | 0.17 | |

Table B1. continued

| Species | Scientific name | Number captured | Percent of total | Total catch |
|---|---|---|---|---|
| Porkfish | *Anisotremus virginicus* | 5 | 0.17 | 2860 |
| Princess Parrotfish | *Scarus taeniopterus* | 5 | 0.17 | |
| Rock Beauty | *Holacanthus tricolor* | 5 | 0.17 | |
| Whitespotted Filefish | *Cantherhines macrocerus* | 5 | 0.17 | |
| Hermit Crab | *Paguroidea spp.* | 4 | 0.14 | |
| Sea Star | *Asteroidea spp.* | 4 | 0.14 | |
| Blackfin Snapper | *Lutjanus buccanella* | 3 | 0.10 | |
| Gray Angelfish | *Pomacanthus arcuatus* | 3 | 0.10 | |
| French Grunt | *Haemulon flavolineatum* | 2 | 0.07 | |
| Redband Parrotfish | *Sparisoma aurofrenatum* | 2 | 0.07 | |
| Trunkfish | *Lactophrys trigonus* | 2 | 0.07 | |
| Yellow Jack | *Caragoides bartholomaei* | 2 | 0.07 | |
| Batwing Coral Crab | *Carpilius corallinus* | 1 | 0.03 | |
| Blue Crab | *Callinectes sapidus* | 1 | 0.03 | |
| Brittle Star | *Ophiuroidea spp.* | 1 | 0.03 | |
| Conch | *Strombus gigas* | 1 | 0.03 | |
| Coral Crab | *Carpilius spp* | 1 | 0.03 | |
| Flying Grunard | *Dactylopterus volitans* | 1 | 0.03 | |
| Gray Triggerfish | *Balistes capricus* | 1 | 0.03 | |
| Great Barracuda | *Sphyraena barracuda* | 1 | 0.03 | |
| Horse-eye Jack | *Caranx latus* | 1 | 0.03 | |
| Ocean Triggerfish | *Canthidermis sufflamen* | 1 | 0.03 | |
| Orange filefish | *Aluterus schoepfii* | 1 | 0.03 | |
| Queen Parrotfish | *Scarus vetula* | 1 | 0.03 | |
| Sargassum Triggerfish | *Xanthichthys ringens* | 1 | 0.03 | |
| Shame-faced Crab | *Calappa spp.* | 1 | 0.03 | |
| Unicorn Filefish | *Aluterus monoceros* | 1 | 0.03 | |
| Whelk | | 1 | 0.03 | |
| Yellowfin Grouper | *Mycteroperca venenosa* | 1 | 0.03 | |

## APPENDIX C. Project Participants

| | |
|---|---|
| *Scientific Personnel:* | |
| Todd Gedamke | NOAA Southeast Fisheries Science Center |
| Jennifer Schull | NOAA Southeast Fisheries Science Center |
| John Walter | NOAA Southeast Fisheries Science Center |
| Simon Pittman | NOAA, NCCOS, Biogeography Program |
| Henry E. Tonnemacher | Seven Seas Ltd. |
| Cynthia Grace-McCaskey | Dept. of Anthropology, University of South Florida |
| Liam Carr | Dept. of Geography, Texas A&M University |
| Sandy Schexnayder | Biologist, St. Croix |
| *Commercial Fishers:* | |
| Tom Daley | |
| Gerson “Nicky” Martinez | St. Croix Commercial Fishermen’s Association |
| Manuel Mercado | |
| Homer Kelly | |
| Benjamin Norris | |
| Eddie Schuster | St. Croix Commercial Fishermen’s Association |
| *Others:* | |
| Carlos Farchette | Caribbean Fishery Management Council |

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