Fishery-Independent Monitoring of Caribbean Spiny Lobster (*Panulirus argus*) in U.S. Virgin Islands National Parks

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SEDAR 103 Working Paper

Fishery-Independent Monitoring of Caribbean Spiny Lobster *(Panulirus argus)* in U.S. Virgin Islands National Parks

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South Florida/Caribbean Network
August 2026

SEDAR 103: U.S. Caribbean Application of Alternate Assessment Methods

Summary

The South Florida/Caribbean Network (SFCN) conducts standardized, fishery-independent monitoring of Caribbean spiny lobster (*Panulirus argus*) in selected National Park Service (NPS) units. The monitoring program was initiated in 2019 to establish repeatable indices of exploited-phase lobster density, occupancy, and size while simultaneously collecting demographic, reproductive, and habitat information.

Although the broader SFCN program also includes Biscayne National Park and Dry Tortugas National Park in Florida, this working paper focuses on surveys conducted in the U.S. Caribbean: Buck Island Reef National Monument (BUIS), Virgin Islands National Park (VIIS), and Salt River Bay National Historical Park and Ecological Preserve (SARI). Florida surveys are mentioned to document the broader program and the consistency of methods across the network; their data are not evaluated here because they fall outside the geographic scope of SEDAR 103.

Survey locations are selected through a stratified-random, spatially balanced design within mapped hardbottom habitats shallower than 30 m. At each site, a team of two divers surveys two adjacent 7.5-m-radius circular plots, providing a combined nominal area of approximately 353 m². Lobsters are counted, visually estimated for carapace length, then captured when practical, and measured, sexed, and examined for reproductive condition. A brief habitat assessment is also conducted. While the survey focus is *Panulirus argus*, opportunistic counts of spotted lobster (*P. guttatus*), queen conch (*Aliger gigas*), and long-spined sea urchin (*Diadema antillarum*) also occur.

Completed surveys include BUIS and SARI in 2019, VIIS in 2021, and repeat surveys at BUIS and SARI in 2024. In 2021, as part of a cooperative agreement with the National Oceanic and Atmospheric Administration (NOAA), deeper aggregate reef habitats between 30 to 50 m on St. John and St. Croix were surveyed as well. Across these events, 277 standard park sites were sampled and 113 lobsters were observed; the exploratory deep survey sampled an additional 72 sites and observed 9 lobsters. Initial analyses demonstrated low density and occupancy, relatively large exploited-phase individuals, high sampling variance, and a substantial number of non-detections. These characteristics are consistent with the challenges identified for U.S. Virgin Islands lobster assessment and monitoring.

The dataset is relevant to SEDAR 103 because it provides standardized observations independent of fishing activity, a probability-based sample frame, explicit measures of survey uncertainty, spatially referenced occurrence data, and individual size and reproductive observations. The current time series remains short and the surveys are limited to park waters, so the indices should not be interpreted as direct estimates of territory-wide abundance. They may nevertheless serve as protected-area abundance indicators, provide information on size structure and reproductive condition, support comparisons among closed or partially protected areas, and inform the design of future U.S. Caribbean surveys.

1. Introduction

The Caribbean spiny lobster (*Panulirus argus*) is distributed throughout the tropical and subtropical western Atlantic and supports economically and culturally important fisheries across the wider Caribbean (Ehrhardt 2005). In the U.S. Virgin Islands, the species is among the territory's most important commercial fishery resources (Olsen et al. 2018). Reliable assessment is complicated by the species' complex life history, wide-ranging larval dispersal, ontogenetic habitat shifts, seasonal movement, sheltering behavior, and spatial aggregation (Herrnkind et al. 1975, Herrnkind 1980).

Fishery-dependent records are indispensable for documenting removals and fleet behavior, but changes in regulations, reporting, market conditions, fishing locations, gear, and fisher participation may affect their interpretation as abundance indicators. Fishery-independent monitoring can complement those records by collecting observations under standardized sampling protocols that are decoupled from fishing activities.

Previous U.S. Virgin Islands lobster studies have provided important local and historical information (see Herrnkind et al. 1975, Olsen et al. 2018), but many were temporally limited, restricted to individual reefs or parks (e.g., Tobias et al. 1988), based on relatively small survey footprints (e.g., Pittman et al. 2008), or implemented using methods that are difficult to compare across time. SEDAR 57 identified the lack of consistent, long-term fishery-independent abundance information as a major limitation for assessment of U.S. Caribbean spiny lobster.

In 2019, the SFCN initiated a long-term lobster monitoring program in network parks with adult lobster populations: Buck Island Reef National Monument (BUIS), Virgin Islands National Park (VIIS), and Salt River Bay National Historical Park and Ecological Preserve (SARI) (Richter et al. 2020). The design was developed to complement the spatial framework used by the National Coral Reef Monitoring Program (NCRMP) reef-fish surveys (Feeley et al. 2025). A common 50 x 50 m grid framework and comparable habitat and depth stratification provide a potential foundation for future co-location or expansion beyond National Park Service waters (Richter and Feeley 2024).

The SFCN program is broader than the geographic scope of this paper. Comparable monitoring has subsequently been completed in Biscayne National Park and Dry Tortugas National Park. Those Florida surveys demonstrate transferability of the protocol and contribute to network-wide management, but their results are not analyzed here. This paper is limited to Caribbean park surveys relevant to SEDAR 103.

The objectives of this working paper are to: (1) describe the U.S. Virgin Islands SFCN lobster survey design and field methods; (2) summarize available survey effort and data products; (3) identify the strengths and limitations of the dataset for assessment; and (4) describe applications of these observations in SEDAR 103 and future U.S. Caribbean monitoring.

1.1 Relevance to SEDAR 103

The monitoring program was designed primarily for long-term park resource monitoring rather than as a territory-wide stock-assessment survey. Nevertheless, several design characteristics are directly relevant to data-limited and alternative assessment approaches: probability-based site selection, standardized survey area, repeatable methods, explicit habitat strata, georeferenced observations, and independent measures of abundance, occurrence, body size, sex, and reproductive condition.

The principal constraint is geographic representativeness. Park waters differ from fished territorial waters in legal protection, enforcement, habitat composition, access, and fishing pressure. Consequently, SFCN estimates should be considered in context and not be expanded to the entire U.S. Virgin Islands. Their most defensible present use is as park-specific fishery-independent indicators and as evidence for the feasibility and sample-size requirements of a broader regional survey.

2. Monitoring Program and Study Area

2.1 South Florida/Caribbean Network program

The SFCN Inventory and Monitoring Division develops and implements long-term protocols for selected natural-resource vital signs in NPS units in southern Florida and the U.S. Caribbean (**Fig. 1**). The Caribbean spiny lobster protocol was initially published in 2018 and updated in 2020 (Richter et al. 2020). Field implementation uses standard operating procedures (https://irma.nps.gov/DataStore/Reference/Profile/2258443) that define preparation, site selection, diver roles, biological measurements, safety practices, data entry, quality assurance, and archiving.

Table 1 provides a brief overview of the NPS units, sample frames, and management contexts of SFCN lobster survey efforts from 2019 to 2024.

3. Survey Design and Methods

3.1 Monitoring objectives

- Evaluate status and trends in relative density of exploited-phase Caribbean spiny lobster.
- Evaluate status and trends in occupancy, defined as the proportion of sampled sites where exploited-phase lobsters are observed.
- Evaluate mean size and characterize the size distribution of exploited-phase lobsters.
- Document sex and reproductive condition when individual lobsters can be captured and examined.

3.2 Target population and exploited phase

The biological target is *Panulirus argus* occurring within the mapped sampling frame during the survey period. Analyses may include all observed lobsters or may be restricted to exploited-phase individuals. Consistent with the published baseline analysis, exploited phase is defined using the U.S. Virgin Islands minimum legal carapace length of 89 mm (3.5 in). Visual length estimates are retained for individuals that evade capture; measured carapace length is preferred when available.

While the survey focus is *Panulirus argus*, opportunistic counts of spotted lobster (*P. guttatus*), queen conch (*Aliger gigas*), and long-spined sea urchin (*Diadema antillarum*) also occur.

3.3 Sampling frame and stratification

The sampling frame is constructed from spatial habitat data and divided into 50 x 50 m grid cells. Surveyable cells are limited to hardbottom habitat shallower than 30 m for standard park surveys. While spiny lobsters use both soft and hardbottom habitats, adults generally seek shelter in hardbottom habitats during daylight hours (Herrnkind et al. 1975, Herrnkind 1980). Thus, the sample frame includes all hardbottom habitat within each park.

Sampling effort is allocated among habitat and depth strata so that all available hardbottom habitats are represented. The specific number and definition of strata vary among parks because habitat composition and depth distribution differ. Randomized site selection within strata preserves the probability-based character of the design.

Rotational park sampling is intended to balance network-wide logistics with the need for repeated observations. Survey timing is kept as consistent as practical, generally around May or June, to reduce confounding from seasonal movement and reproduction.

3.4 Plot configuration

Within each stratum, grid cells (primary sample units) are randomly selected for sampling. Within a selected grid cell, the divers are deployed on the first hardbottom habitat encountered to establish two adjacent circular plots (**Fig. 2**). Each plot has a radius of 7.5 m and an area of approximately 176 m²; the

paired plots therefore provide a nominal sampled area of approximately 353 m². The configuration matches the footprint used in related reef-fish visual surveys.

3.5 Field survey sequence

Site approach and verification: Navigate to the randomized grid cell, confirm hardbottom present visually from surface or with sonar.

Plot establishment: Dive team established the two adjacent circular plots on first hardbottom encountered after descent.

Standardized search: Two divers systematically search the assigned plot areas, including ledges, crevices, cavities, and other shelters likely to contain lobster.

Observation and size estimation: Record each observed lobster and visually estimate carapace length before capture is attempted.

Capture and biological measurements: When feasible, capture the lobster using snare or hand-net, measure carapace length, determine sex, assess eggs and spermatophore condition, and record relevant observations.

Release: Release captured lobsters at or near the point of capture immediately after processing.

Habitat and site documentation: Complete brief habitat assessment.

3.6 Variables collected

Table 2 provides the variables collected during SFCN lobster surveys.

3.7 Quality assurance, data management, and publication

Surveyors are trained in plot establishment, species identification, visual size estimation, capture techniques, sex determination, reproductive observations, and data recording. Field forms and database validation rules are used to reduce missing or internally inconsistent entries.

After fieldwork, records are reviewed for completeness, valid site and stratum identifiers, coordinate consistency, biologically plausible measurements, duplicated records, and agreement between plot-level and individual-level records. Corrections are documented according to SFCN data-management procedures.

Approved data are stored in a relational SQL database and published through the NPS DataStore. The published data package provides the authoritative public archive for the monitoring record: https://irma.nps.gov/DataStore/Reference/Profile/2316604

4. Analyses

This section defines the primary analytical products that can be generated from the survey. Calculation of metrics need to include the appropriate survey weights from stratum areas documented for each event.

4.1 Relative density

Site-level density is calculated as the number of observed lobsters divided by the surveyed area, expressed as lobsters ha^{-1}. Park-event estimates are calculated using the stratified survey design so that habitat strata contribute in proportion to their mapped area. Density may be reported for all observed lobsters and separately for exploited-phase lobsters.

4.2 Occupancy

Occupancy is defined here as the design-based proportion of sites with one or more lobsters observed. This metric describes spatial occurrence within the sampled habitat and can be more stable and interpretable than mean count when counts are highly aggregated.

4.3 Size metrics

Measured carapace length is used when available; visual estimated length is used for individuals that evade capture. Products include mean exploited-phase size, minimum and maximum observed size, and size-frequency distributions.

4.4 Uncertainty and bootstrap procedures

The published baseline analysis uses stratified non-parametric bootstrap using 10,000 samples with replacement to calculate confidence intervals.

4.5 Sampling performance

Low encounter rates and gregarious spatial distributions can produce high variance. Simulation or resampling can be used to evaluate the relationship between survey sample size and the coefficient of variation of the density index. This analysis is useful both for interpreting current precision and for the potential of planning a broader U.S. Caribbean monitoring program.

5. Results

5.1 Survey effort

Survey effort and observed lobsters from SFCN sampling missions between 2019 and 2024 is provided in **Table 3**.

5.2 Spatial distribution

Figs 3, 4, & 5 present maps of all lobster surveys conducted in BUIS, SARI, and VIIS respectively between 2019-2024. Small black circles indicate where surveys occurred. Larger colored circles indicate the total number of lobsters observed at each survey, proportional in size to the number of lobsters seen. Light red shading on the map indicates hardbottom habitat that is included in the sample frame.

5.3 Baseline 2019-2021 findings

The published baseline study reported low lobster density and low site occupancy in all three U.S. Virgin Islands parks. Across parks, exploited-phase density estimates ranged approximately from 3.9 to 7.3 lobsters per hectare, and exploited-phase occupancy was approximately 0.11 to 0.12 (**Table 4, Figs. 6 & 7**)

Despite low encounter rates, exploited-phase lobsters were relatively large. The published park-specific average exploited-phase sizes were approximately 109 mm at BUIS, 109 mm at SARI, and 125 mm at VIIS (**Fig. 8**). These results should be interpreted cautiously because the number of measured or estimated individuals was small.

Baseline survey performance analysis showed that many additional sites would be needed to achieve low coefficients of variation under similarly low density and aggregation. This result is important for interpreting the present indices and for designing surveys intended to detect change over short time intervals.

5.4 Repeat surveys in 2024 (BUIS & SARI)

Repeat surveys were completed at BUIS and SARI in 2024 using the established protocol. Survey effort and total observations are shown in Table 3. Density and occupancy estimates remain low and within the range of baseline estimates from 2019. Across parks, exploited-phase density estimates were approximately 3.9 to 5.3 lobsters per hectare at both BUIS and SARI, and exploited-phase occupancy was approximately 0.19 (**Table 4, Figs. 6 & 7**).

Despite low encounter rates, exploited-phase lobsters still were relatively large and within the range of baseline values: approximately 118 mm at BUIS and 102 mm at SARI (**Fig. 8**). These results should be interpreted cautiously because the number of measured or estimated individuals was small.

5.5 Size structure and reproductive observations

A size-frequency plot is presented in **Fig. 9**, pooling all lobster observations from surveys conducted between 2019 and 2024. Observations are pooled because overall sample size for any one location is low. The red vertical dashed line identifies the 89-mm exploited-phase threshold.

5.6 Sampling precision

The sampling-performance curve from pooled U.S. Virgin Islands surveys is provided in **Fig. 10**. The curve may be used to estimate the number of samples required to achieve a target coefficient of variation under the current sample design. Approximately 152 surveys are required to achieve a 20% CV, a common target in fisheries-independent sampling.

6. Discussion

The SFCN monitoring program has now completed five survey events in three NPS units in the U.S. Virgin Islands, providing the repeatable fishery-independent estimates of Caribbean spiny lobster density, occupancy, and exploited-phase size. Across all surveys, lobster densities and occupancy were consistently low, exploited-phase individuals were generally large, and observations exhibited substantial spatial aggregation. These characteristics have important implications for both interpretation of the current dataset and the design of future monitoring efforts.

Although the current time series is limited, repeat surveys completed in BUIS and SARI suggest that the monitoring design produces repeatable estimates using a standardized sampling framework. The consistency of survey methods across parks and years provides a foundation for future trend analyses as additional monitoring events become available. At present, however, the dataset is best viewed as a series of standardized park-level indicators rather than a territory-wide index.

6.1 Strengths

Surveys are conducted using a standardized protocol and a probability-based, stratified random sampling design, allowing density, occupancy, and size estimates to be compared consistently among parks and over time. Opportunistic observations of other ecologically and commercially important species, such as queen conch (*Aliger gigas*), are collected during the same surveys. While currently limited to NPS units, the sampling design is compatible with broader regional reef monitoring programs, providing opportunities to improve efficiency through coordinated survey efforts while expanding the spatial coverage of fishery-independent monitoring.

6.2 Geographic limitations

Current surveys are restricted primarily to NPS waters and therefore sample a non-random subset of the U.S. Virgin Islands stock distribution. Park boundaries may encompass different habitat, exploitation, enforcement, and access conditions than adjacent territorial waters. The data should not be expanded outside the sampling frames without a defensible model or expanded survey.

6.3 Detection and behavioral limitations

Caribbean spiny lobsters shelter during daylight and can be difficult to detect in structurally complex habitat. The protocol standardizes search methods but does not independently estimate detection probability. Calculated densities should therefore be interpreted as relative indices, rather than estimates of absolute population density. Detectability may vary with habitat complexity, diver experience, sea conditions, animal behavior, and refuge depth.

6.4 Low density and aggregation

Low encounter rates and gregarious distribution lead to many zeros and occasional sites with multiple individuals. Consequently, confidence intervals are relatively wide and greater sampling effort is required to detect modest temporal changes. An increased number of samples can help reduce the variance in future surveys.

6.5 Rotational sampling and short time series

The rotational schedule produces multiyear gaps between park surveys. At the time of this writing, only BUIS and SARI have repeat sample events. This design is appropriate for long-term monitoring but limits annual trend estimation and complicates comparison with annual fishery removals or environmental events.

Although originally developed for long-term resource monitoring rather than stock assessment, the SFCN monitoring program provides standardized fishery-independent observations collected using a probability-based sampling design. The dataset complements fishery-dependent information by providing independent estimates of relative density, occupancy, and exploited-phase size within protected areas of the U.S. Virgin Islands. Continued monitoring will improve the temporal resolution of these indices and increase their value for evaluating long-term population change.

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Tables

Table 1. NPS units, management context, and survey and survey events included in this working paper.

Park code	National Park Service unit	Island	Management context	Survey events included
BUIS	Buck Island Reef National Monument	St. Croix	No-take marine protected area; managed by NPS	2019, 2024
SARI	Salt River Bay National Historical Park and Ecological Preserve	St. Croix	Jointly managed by NPS and VI Gov't; fishing restricted	2019, 2024
VIIS	Virgin Islands National Park	St. John	Recreational lobster harvest permitted; managed by NPS	2021
USVI Deep	Exploratory deep-water survey	St. Croix & St. John	Spanned multiple managed zones; survey focus on deep reef habitat, not management area	2021

Table 2. Variables groups collected in SFCN Caribbean spiny lobster surveys.

Category	Variable	Description / analytical role
Survey identifiers	Park, event, date, site, plot, stratum	Uniquely identify observations and preserve the sample design.
Location and environment	Coordinates, depth, habitat	Characterize the sampling frame and support spatial and habitat analyses.
Occurrence and density	Presence and number observed	Calculate occupancy and density indices
Size	Estimated and measured carapace length	Characterize exploited phase, mean size, and size-frequency distribution.
Demography	Sex	Describe observed sex ratios when sex can be determined.
Reproductive condition	Egg presence/development and spermatophore condition	Describe reproductive condition of captured females.
Observation quality	Capture status, measurement source, observer notes	Identify visual estimates, measured individuals, and potential data limitations.

Table 3. Survey effort and observed lobsters from SFCN sampling missions between 2019 and 2024. The totals distinguish the standard park monitoring surveys from the exploratory deep-water survey.

Survey area	Year	Sites	Strata	Lobsters observed	Role
BUIS	2019	76	4	23	Baseline park survey
SARI	2019	32	2	27	Baseline park survey
VIIS	2021	72	5	31	Baseline park survey
USVI Deep	2021	72	2	9	Exploratory deep-water application
BUIS	2024	76	4	19	Repeat park survey
SARI	2024	21	2	13	Repeat park survey
Standard Caribbean park surveys	*2019-2024*	*277*	-	*113*	*Combined NPS unit dataset*
Including exploratory deep survey	*2019-2024*	*349*	-	*122*	*Expanded descriptive total*

Table 4. Estimates for total lobster density, exploited-phase lobster density, exploited-phase occupancy, and mean size (carapace length = CL) in the exploited-phase. Error presented as 95% confidence intervals calculated by non-parametric bootstrap with 10,000 replications.

Park	Year	Total lobster ha^{-1} [95% CI]	Exploited lobster ha^{-1} [95% CI]	Exploited occupancy [95% CI]	Mean exploited CL [95% CI]
BUIS	2019	5.7 [2.5, 9.4]	3.9 [1.4, 7.0]	0.12 [0.04, 0.22]	109 mm [101,118]
BUIS	2024	5.5 [2.9, 8.5]	5.4 [2.7, 8.2]	0.19 [0.10, 0.29]	118 mm [112, 124]
SARI	2019	16.5 [4.9, 30.7]	7.3 [0.3, 17.2]	0.12 [0.01, 0.26]	109 mm [104, 115]
SARI	2024	20.1 [1.1, 54.3]	5.3 [1.1, 10.8]	0.19 [0.04, 0.38]	102 mm [93, 112]
VIIS	2021	8.1 [3.5, 13.7]	4.9 [2.3, 7.9]	0.11 [0.06, 0.16]	125 mm [117, 135]

Figures

Figure 1. National Park Service units included in the SFCN Caribbean spiny lobster monitoring program. Buck Island Reef National Monument and Salt River Bay National Historical Park and Ecological

Preserve are on St. Croix; Virgin Islands National Park is on St. John. Florida park units monitored under the broader SFCN program (Biscayne National Park and Dry Tortugas National Park) are not included in the analytical scope of SEDAR 103.

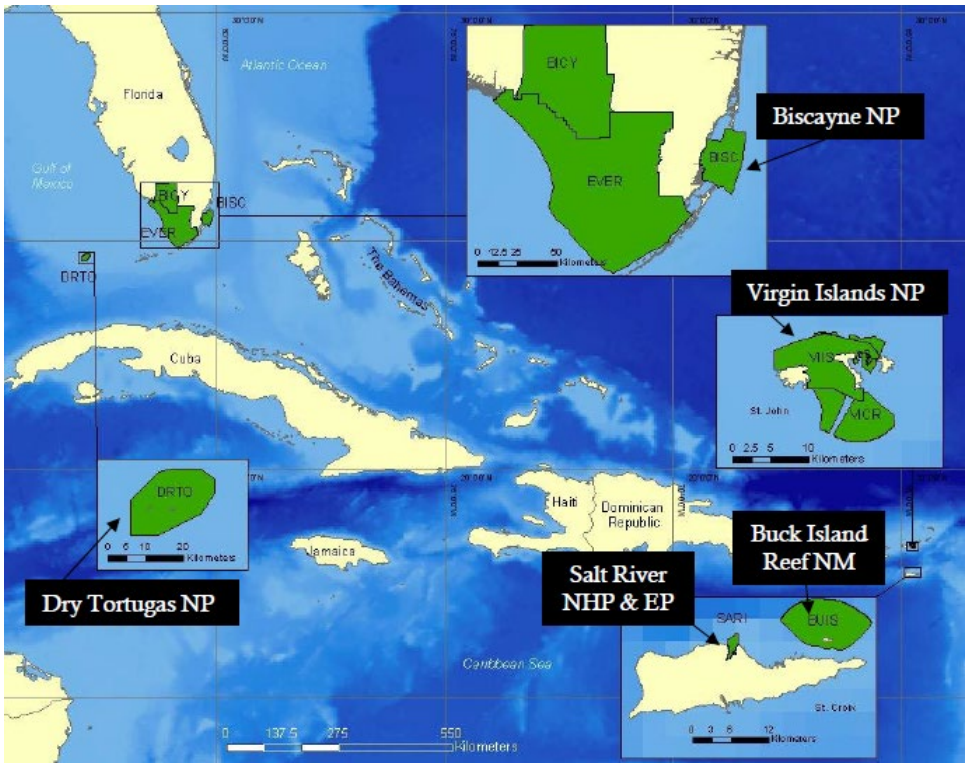


Figure 2. Paired circular-plot configuration used for Caribbean spiny lobster visual surveys with a selected 50 x 50 m grid cell (primary sample unit). Each plot has a 7.5-m radius and an area of approximately 176.7 m², for a combined nominal survey area of approximately 353.4 m² per site.

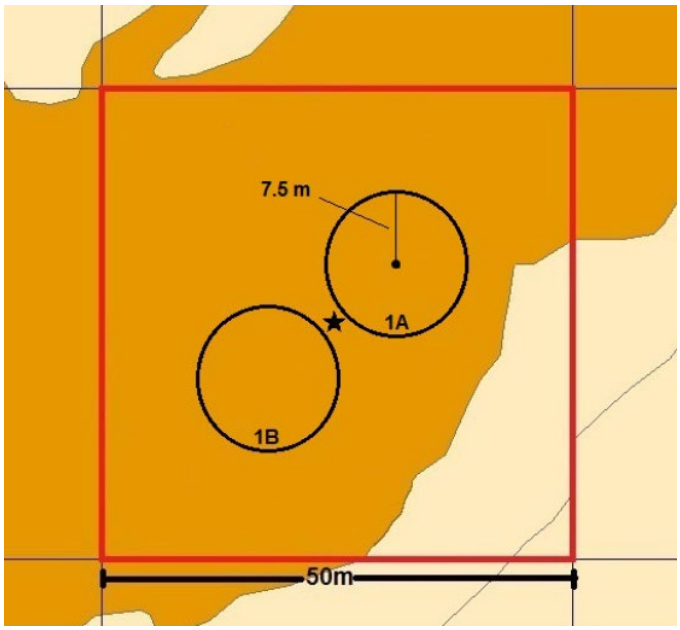


Figure 3. Site-level Caribbean spiny lobster observations in Buck Island Reef National Monument during 2019, 2021 deepwater surveys, and 2024. Symbols show all sampled sites, including zero observations, and are scaled by the number of lobsters observed.

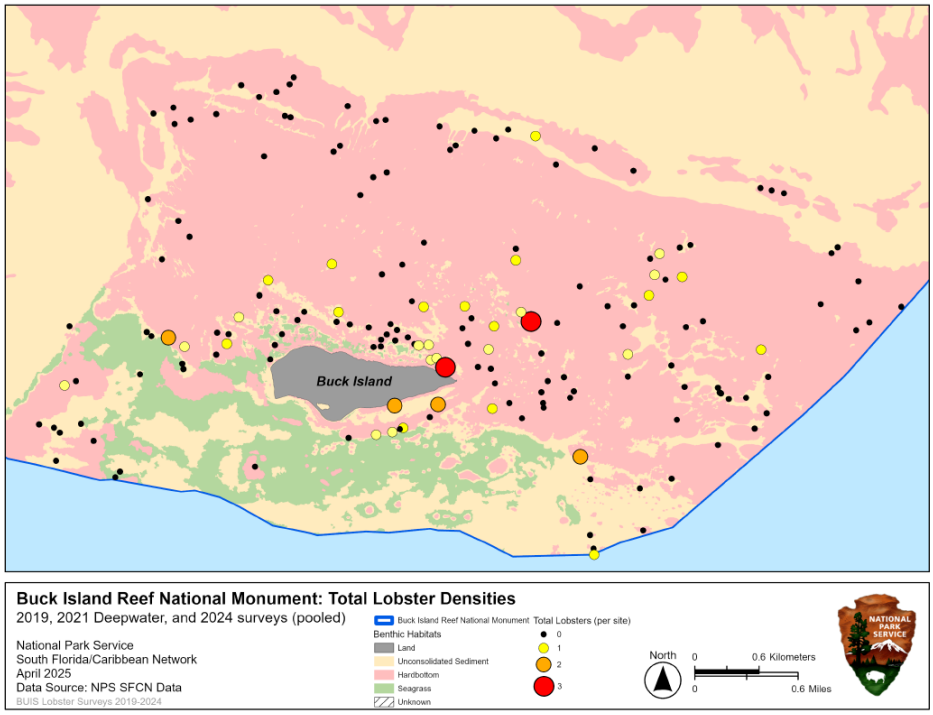


Figure 4. Site-level Caribbean spiny lobster observations in Salt River Bay National Historical Park and Ecological Preserve during 2019 and 2024.

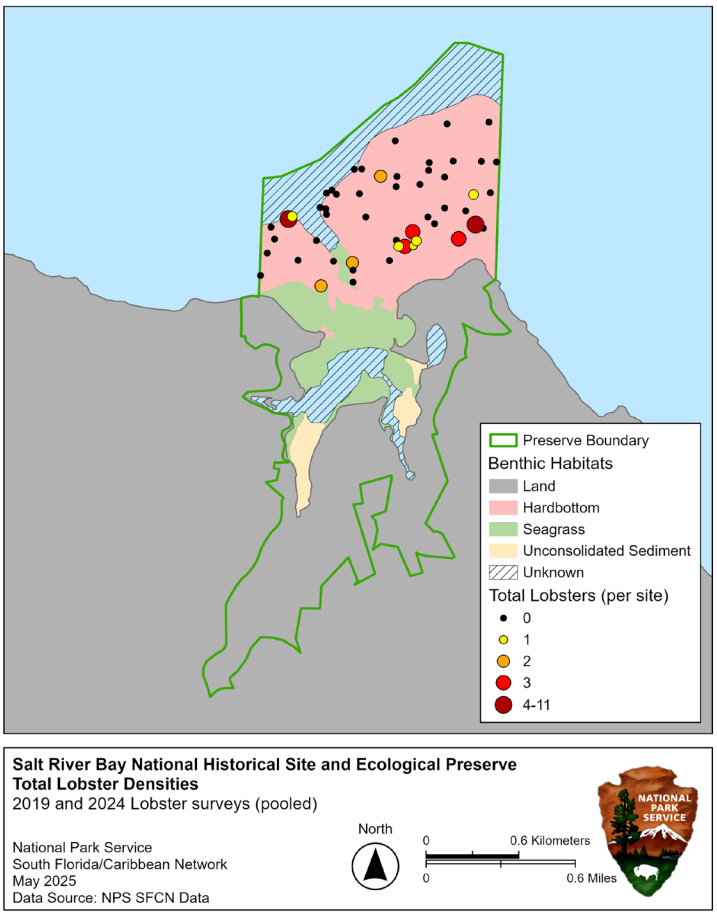


Figure 5. Site-level Caribbean spiny lobster observations in Virgin Islands National Park during 2021.

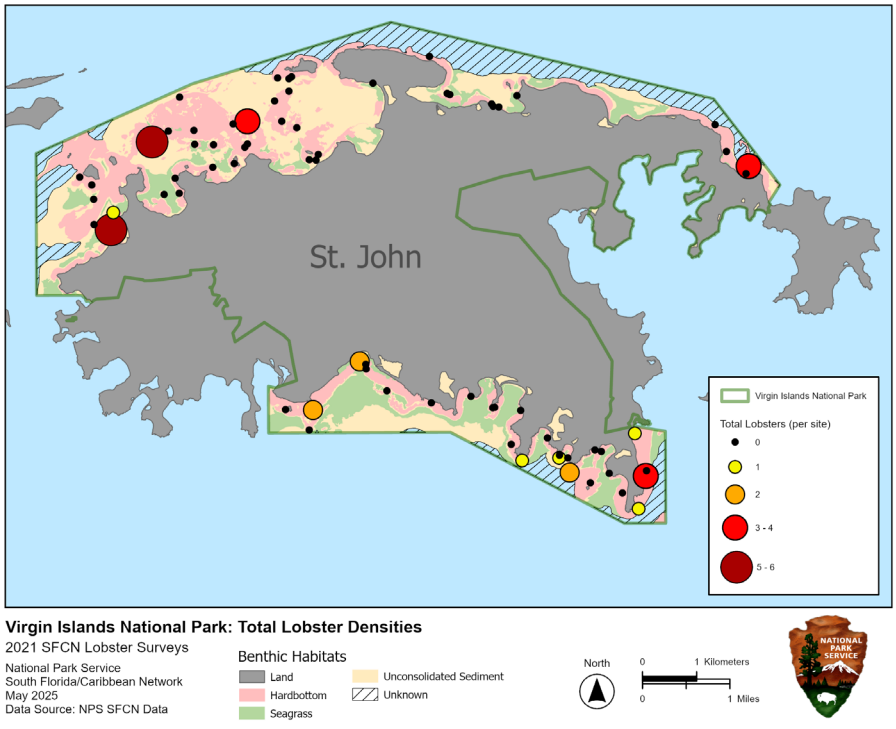


Figure 6. Estimated densities of exploited-phase and total lobsters observed in BUIS (2019 & 2024), SARI (2019 & 2024), and VIIS (2021). Error bars are 95% confidence intervals.

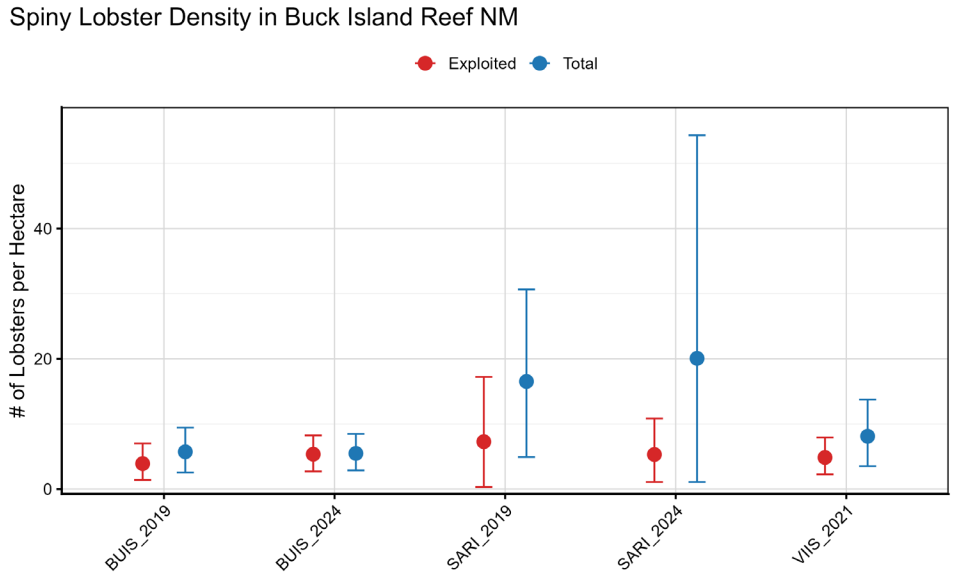


Figure 7. Estimated occurrence of exploited-phase and total lobsters observed in BUIS (2019 & 2024), SARI (2019 & 2024), and VIIS (2021). Error bars are 95% confidence intervals.

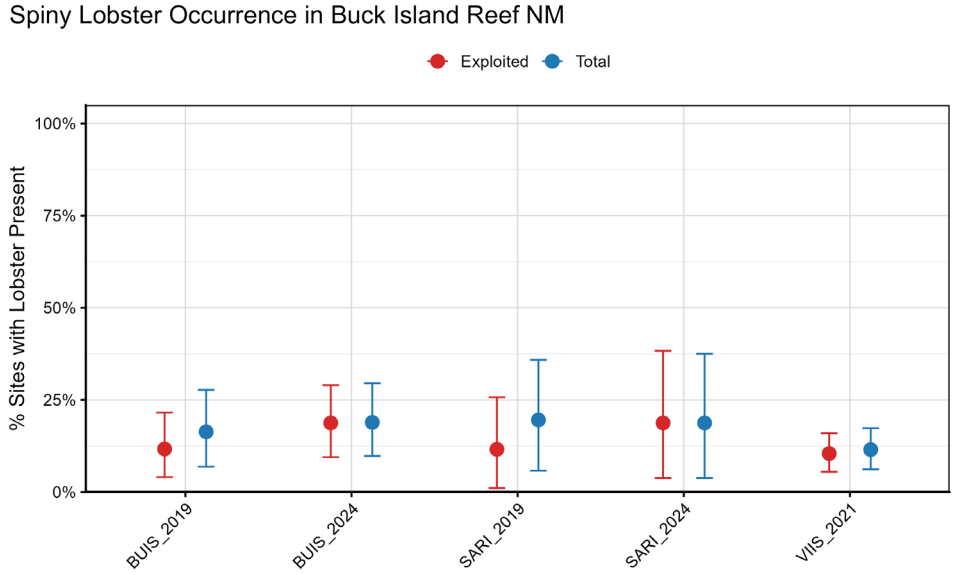


Figure 8. Mean size of exploited-phase lobsters observed in BUIS (2019 & 2024), SARI (2019 & 2024), and VIIS (2021). Error bars are 95% confidence intervals.

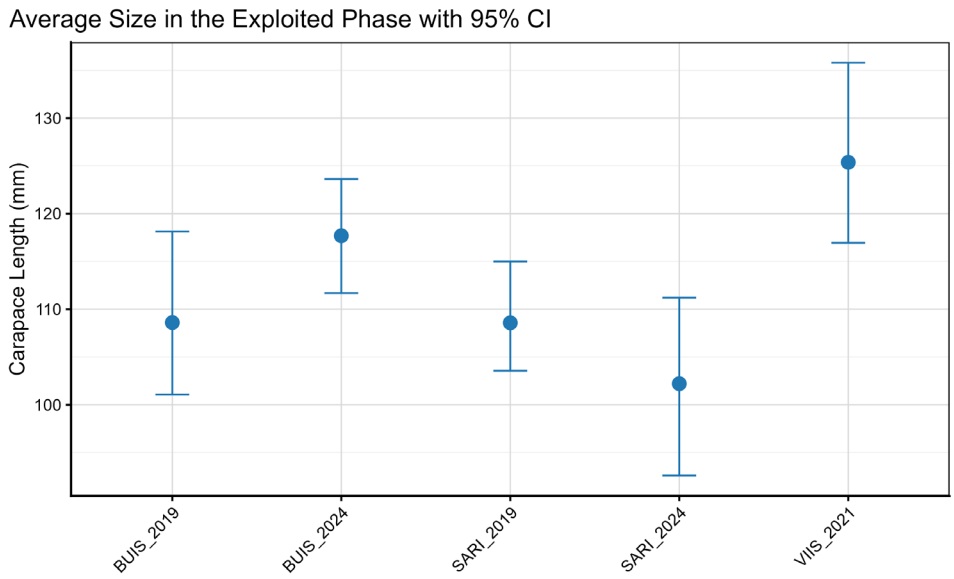


Figure 9. Carapace-length distribution of observed Caribbean spiny lobsters in U.S. Virgin Islands National Park Service surveys. Measured lengths are used when available and visual estimates are used when lobsters evaded capture. The vertical reference line marks the 89-mm exploited-phase threshold.

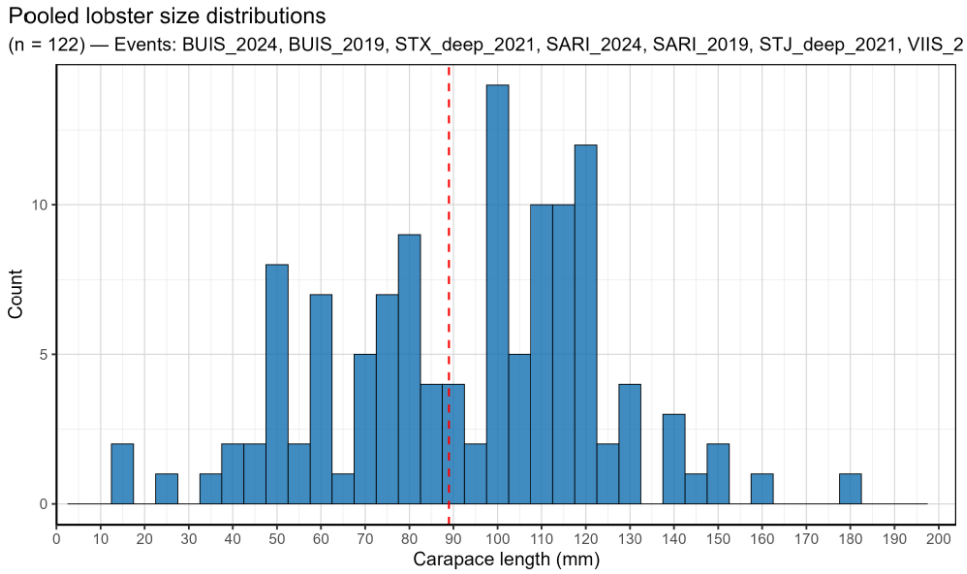
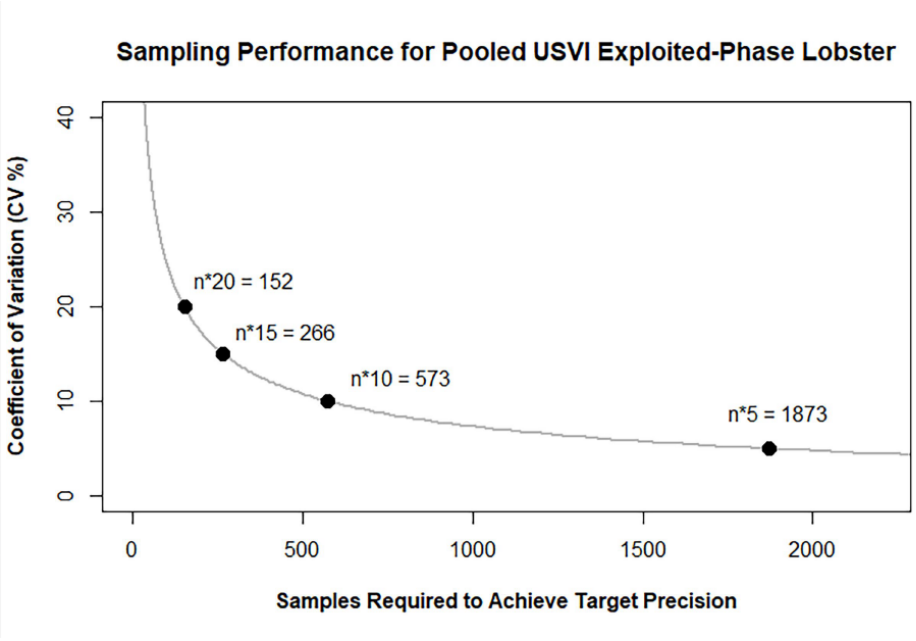


Figure 10. Sampling-performance relationship between survey sample size and the coefficient of variation of the exploited-phase density index, based on pooled baseline observations and the existing stratification scheme.


Sampling Performance for Pooled USVI Exploited-Phase Lobster
Coefficient of Variation (CV %)
0
10
20
30
40
n*20 = 152
n*15 = 266
n*10 = 573
n*5 = 1873
0
500
1000
1500
2000
Samples Required to Achieve Target Precision