Collaborative Fisheries Science with a SMILE
("Size Matters: Innovative Length Estimates")

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Background

Management of reef fish populations is challenging largely due to their multi-species nature and the complex reef ecosystems in which these species inhabit, which is further complicated by limited resources for data collection. Traditional fisheries management strategies have predominantly focused on single species management to regulate harvest of fished species, whereas ecosystem-based management applies a more holistic approach through consideration of the broader ecosystem. However, these ecosystem-based management approaches typically have more extensive data needs, and fisheries managers often lack sufficient resources to collect data on federally managed stocks. Length-frequency estimation is a common source of demographic data for fisheries assessments, as these data can inform length-at-age, population age structure, biomass, population change, and length-based spawning potential ratio (Ault et al. 1998). Traditional length estimation methods require handling or harvesting the fish, which can impact local fish populations, and may represent a limited distribution of fish sizes and species due to harvest restrictions, thus creating a knowledge gap for underrepresented fishes and lengths.

Non-traditional data sources, like citizen science data streams, can be used to affordably help fill data gaps and supplement existing data collection programs. Citizen science is a NOAA science and technology focus area (2021), as it can expand upon traditional data sources through reporting, monitoring, and managing data collections, and data processing across diverse taxa, such as birds (Horns et al. 2018), invasive species (Clements et al. 2021) and fishes (Greenberg et al., 2024; Figure 1). In particular, divers and snorkelers represent a group of marine resource users that frequent marine systems enough to document changes in fish populations and the marine environment, yet have been a historically underutilized data source. Citizen science programs such as Reef Environmental Education Foundation's (REEF) Volunteer Fish Survey Project empower the public to generate monitoring data and promote active participation in resource management science.

Since 1993, REEF's Volunteer Fish Survey Project (VFSP) has become one of the most effective marine citizen science databases through monitoring data on fish populations at local and global scales (REEF.org//programs/volunteer-fish-survey-project; >15,000 sites surveyed worldwide). REEF trains citizen scientists (recreational SCUBA divers and snorkelers) in fish identification to perform roving diver surveys during recreational dives to provide observational data of diversity and relative abundance of marine fish (Schmitt and Sullivan, 1996). Roving diver surveys involve trained divers and snorkelers recording every observed fish that can be positively identified throughout a site and for the duration of their dive. Relative abundance is estimated by divers via four categories for each species: single (1 individual), few (2-10), many (11-100), and abundant (>100). Each diver/snorkeler also reports dive metadata (e.g., bottom time, current, visibility, depth, habitat). REEF has a passionate and broadly distributed membership of over 80,000 citizen scientists and has amassed >300,000 reef fish surveys worldwide. These surveys track fish population trajectories similar to that of NOAA's National

Coral Reef Monitoring Program (Brandt et al., 2009; Greenberg et al., 2024) and have contributed to over 130 scientific publications (reef.org/news/publications). Publicly available data reports include location, density (based on relative abundance and number of surveys, above), and sighting frequency (measure of how often a species is observed). More detailed reports are available by request. All data submissions undergo automated error checking of any unusual sightings upon data entry and via final staff review as QA/QC.

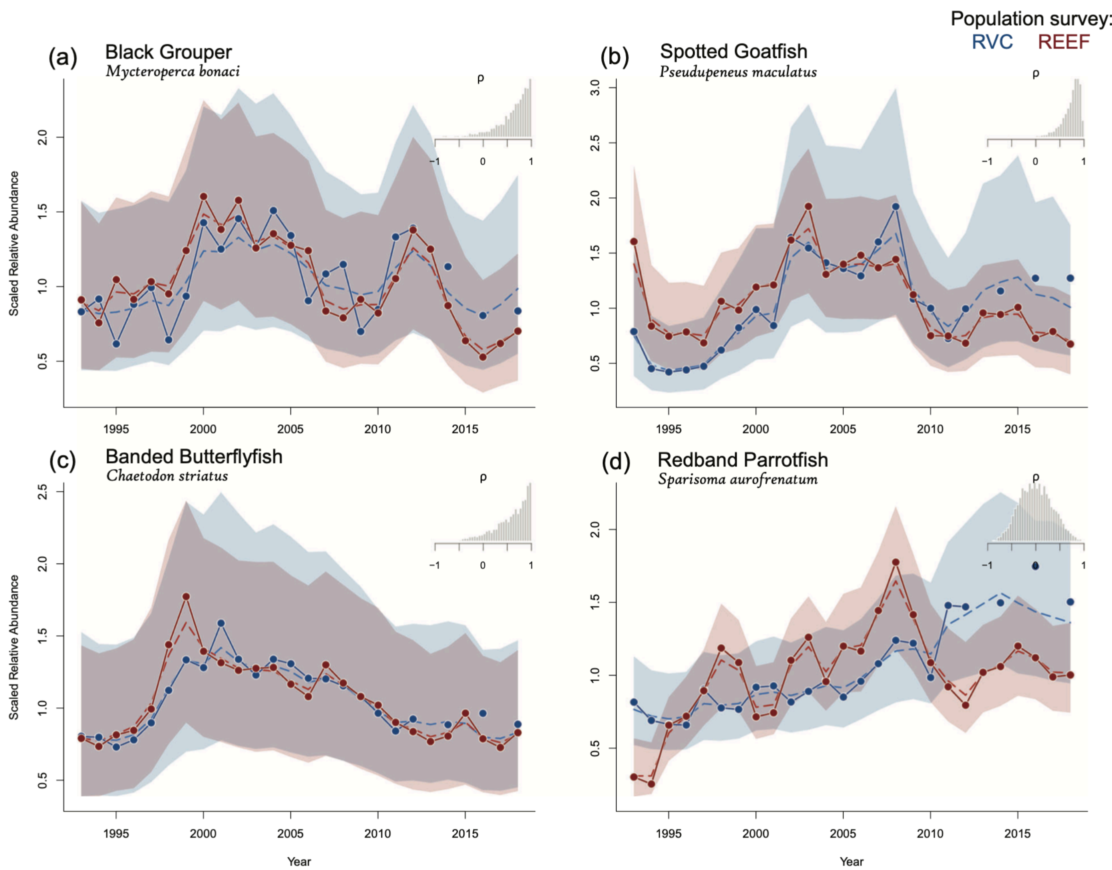

Figure 1. Examples of relative abundance time-series estimated from RVC surveys (blue) and REEF fish surveys (red) of four species, taken from Greenberg et al. 2024. Solid lines and points represent median estimates of the annual expected abundance (*x*) with both process and measurement deviance, while dashed lines indicate model-estimated population state (*x*), with only process deviance. Shaded areas represent 90% Bayesian credible intervals for the latent population states. Time-series plots for all species comparisons are available in the manuscript Appendix.

Project Summary

While relative abundance is a key datum of REEF's VFSP surveys, length data have not been previously incorporated. Length frequency is an important metric for assessment of data-limited species and can help detect changes in reef fish population status (Heppell et al. 2012). To address these needs, the pilot study of the SMILE (Size Matters: Innovative Length Estimates) project equips citizen scientists with a single laser-mounted, affordable, waterproof camera (“FishSenseLite”, “FSL”) to collect images *in situ.* These images are then post-processed through an AI workflow to calculate fork length.

As a citizen science and fisheries ecology focused project, the primary goals and components of the SMILE project are:

1. Produce a cost-effective tool to obtain high quality, high accuracy *in situ* length estimation of data-limited fish species.
2. Engage citizen scientists’ involvement in fisheries science.
3. Supplement fisheries stock assessments with reliable length data.

These length data can also be used to estimate age and biomass of focal species. This will directly and efficiently contribute data to fisheries assessments by providing metrics that inform the status of local stocks of data-limited species to support informed decisions regarding broader stock management. Furthermore, due to the non-extractive methods provided by the FishSenseLite cameras, citizen scientists can gather valuable data both within and outside protected areas to provide insight into the efficacy of protected areas. This project provides length-based life history data of key fisheries taxa to help fill priority data gaps for reef fishery stock assessments and dive metadata that reflect correlative coral reef conditions, through cooperative research with spearfishers, diver operators, and community stakeholders to collect these data, thus promoting active participation in fisheries science. These efforts have been focused on collecting fish length data that enhances information available to managers and stock assessment scientists for various reef-associated federally managed target species, including parrotfishes to reflect ecological trends relative to herbivorous and occasional-corallivorous fishes, in the Florida Keys (Table 1).

The SMILE project is supported by a NOAA Coral Reef Conservation Program grant (award # FNA22NMF4410182) to successfully develop and pilot test the user-friendly camera system, and promote citizen science participation in the Florida Keys in partnership with the South Atlantic Fishery Management Council (SAFMC), University of California San Diego (UCSD) and Scripps Institute of Oceanography (Scripps), Oregon State University (OSU), Southeast Coastal Ocean Observing Regional Association (SECOORA), and Tetra Tech/Axiom Data Science. Additionally, the project receives guidance from a stakeholder group that consists of representatives from NOAA, Florida Keys National Marine Sanctuary (FKNMS), Florida Fish and Wildlife Conservation Commission (FWC), Nature Analytics consulting group, and citizen scientists. Citizen scientists (divers, snorkelers, spearfishers) and the stakeholder panel are an integral part of the co-creation of this project. In addition to end data users, they are the primary target audiences and have provided vital feedback on the distribution of target species, camera hardware and user experience, and methodology and site selection, respectively.

Through this generous support, the SMILE project achieved much success in developing and field testing the camera system and bringing awareness to the project and fisheries data needs through citizen science engagement (webinars, chartered dives) and communications (e.g., conference presentations, NOAA CRCP features, popular press). Thus far, the project has collected length data on thousands of individual fish of eleven target species (Table 1) identified as SAFMC data priorities, by 46 different volunteers performing over 295 dives. In addition, these species are generally large-bodied and easy to identify for divers of any identification experience level.

Table 1. List of target species and descriptions for inclusion in the SMILE pilot project.

Common Name	Scientific Name	Description
These predatory species are part of the South Atlantic's snapper grouper complex of managed reef fishes. Many of them perform ontogenetic shifts, are sequential hermaphrodites, and managed by both state and federal entities.		
Mangrove/Gray snapper	Lutjanus griseus	This mesopredator conducts an ontogenetic shift from inshore nursery habitat to offshore reefs and experiences harvest pressure in both habitats. This species is a high data collection priority for the SAFMC, as it has yet to have a stock assessment for the region.
Mutton snapper	*Lutjanus analis*	This long-lived mesopredator also performs ontogenetic habitat shifts and reaches larger sizes than L. griseus. It is also considered a high data collection priority for SAFMC, with a recent stock assessment (SEDAR 79).
Black grouper	*Mycteroperca bonaci*	Like many groupers, this predator demonstrates strong site fidelity and experiences intense harvest pressure that is managed as a single stock, and is a high priority data collection species for SAFMC.
Goliath grouper	*Epinephelus itajara*	This is the largest grouper species in the Atlantic basin, which has undergone recent management changes. Considered a protected species in the US due to overfishing since (SEDAR 47; 2016) 1990, a lottery permit (200/year; $150/Florida resident) process to catch one fish (24"-36") per season has been implemented by the state of Florida since 2023. Stock assessment reviewers have indicated that additional indices of abundance, lengths, and spatial information would improve future stock assessments.
Nassau grouper	*Epinephelu striatus*	This predator is considered federally threatened, and critically endangered throughout its range (IUCN), thus harvest of this species is prohibited. Length data provide better insight on population status and management efficacy in this region.
Red grouper	*Epinephelus morio*	This data-limited predator is considered overfished and is managed as two stocks (Gulf and Atlantic; Atlantic SEDAR 53; 2017) with an updated SEDAR in the near future. Reviewers recent stock assessments indicated that additional indices of abundance, lengths, and spatial information would improve future stock assessments.
Hogfish	*Lachnolaimus maximus*	This benthic carnivore experiences intense harvest pressure and are data limited. The Hogfish stock off the FL Keys is overfished and undergoing overfishing based on the most recent assessment (SEDAR 37). Management measures were enacted in 2018 which restricted harvest which will limit the amount of data available for future assessments. Data from this project provide an opportunity to contribute to the next Hogfish assessment.
Parrotfish These species provide a good representative for a lower trophic level, in addition to being an ecosystem indicator. These species are also frequently encountered on dives in the Keys and provide a good size range that may not be captured with the predator species, thus making suitable subjects for citizen scientists. Parrotfish are not federally managed in the U.S. South Atlantic, thus lack landings dat, but information on these species would be a valuable component of future ecosystem analyses.		
Stoplight parrot	*Sparisoma viride*	This species is a true, strict herbivore and thus provides a good indicator of reef health. This species presents distinct color phases that correspond with size, age, and population sex structure. This species is restricted to the Tropical Western Atlantic.
Rainbow parrot	*Scarus guacamaia*	The IUCN lists this large herbivorous parrotfish as "near threatened," as it is dependent upon both mangrove shorelines and coral reef habitats.
Midnight parrot	*Scarus coelestinus*	This species is considered data deficient (IUCN), but can exhibit local site abundance, often foraging in groups on algae and opportunistically on small invertebrates.
Blue parrot	*Scarus coeruleus*	This species also often forages in groups, primarily on algae covering corals.

Lastly, a formal user survey for the SMILE project has been developed to investigate demographics, motivations, and barriers of citizen scientists' participation in the SMILE project specifically, as well as in conservation technology-based citizen science programs more broadly. The survey is provided to potential participants and to individuals following project involvement. This survey is conducted in collaboration with social scientists from Colorado State University and the Florida Fish and Wildlife Conservation Commission (full survey link: https://colostate.az1.qualtrics.com/jfe/form/SV_8ex46Y1PbsdBJum). This will advance the project's citizen science efforts beyond the pilot stage and enhance its design, with findings to be presented in a peer-reviewed manuscript.

Project Methodology

To collect images for length estimation, divers simply point the camera mounted laser at the lateral center of a target fish and capture images in burst mode from a distance of up to 5 meters. Additional data collected during test dives include: time and date, location, bottom time, depth and temperature (continuous from dive computers), average depth, dive conditions (visibility, current, as reported by divers) and diver name and camera number. When able, GPS units are towed for the duration of the dive. The original FishSenseLite design developed by engineers at UCSD (e4e.ucsd.edu/fishsense/) and used in the SMILE pilot project utilizes one fixed laser, allowing fish to be measured through a depth of field calculation after precise calibration. The images and raw image files are then uploaded to perform post-processing analysis of laser position, fish head and tail, and fish species to estimate length of a focal fish through an AI workflow.

This workflow relies on the known relationship between the FSL camera and its rigidly attached laser. The parallax (or change in perspective) between the camera and the laser means there is a strong relationship between the position of the laser in the image and the distance an object is from the camera. By modeling this relationship, the distance away from the fish is measured. The laser is detected in the image with knowledge of the laser characteristics: a) color, b) expected position, and c) approximate shape of the laser. Using these characteristics, as well as some fine-tuning, it is then possible to classify the likelihood that any pixel within the image is a laser. Fish measurement requires detecting the head and tail (fork length). First, the outline of the fish is detected with the assistance of existing AI models to determine which pixels are fish with the laser, and which pixels are something else. Pixels that match the focal fish are then combined with knowledge of laser location to mark the fish for measurement. The distance between the fish and the camera then acts as a scale factor (i.e. the image coordinates of the head and tail are used to calculate a unit vector, and scaled using coordinates from the laser) to convert the relative size in the photo to a real-world size.

A new laser prototype is being developed with industry partners at Backscatter Underwater Photo and Video that will be a more robust and adaptable laser design. While the current camera-laser system in the pilot study has proven effective, numerous challenges have been encountered with the durability of the five off-the-shelf laser models tested to date. These issues include water ingress, insufficient laser intensity, limited battery life, and the need for a more secure mounting mechanism. The new laser design being developed will feature a factory-sealed construction, ultimately tested to a depth of 100 meters, with a five-hour battery life, an enclosed magnetic charger, and a protected on/off button—innovations that will significantly reduce the risk of flooding. This design differs from the original single fixed laser design currently being used in phase 1 of the SMILE project by incorporating two high-lumen green lasers, 25mm apart, precisely calibrated to run parallel to enable more accurate length analysis while minimizing the need for frequent recalibration. It will feature a toggle between single and dual-laser modes, enhancing its appeal to recreational divers by allowing it to function as a standard laser pointer when needed. It will also incorporate a fixed cold shoe mount that will be adaptable for most underwater camera housings.

Data Validation and Preliminary Results

The SMILE project is wrapping up the pilot stage in 2025, where we continue to progress system validation, hardware robustness, and efficient delivery of length estimation through a developed AI workflow. In an effort to address some of the challenges associated with citizen science-driven data, and help ensure the data collected meet their intended use, these methods have been validated using paired stereo-video cameras to the FSL cameras during field tests (i.e., live fish) and with known-sized objects (e.g., models of fish, Figure 2).

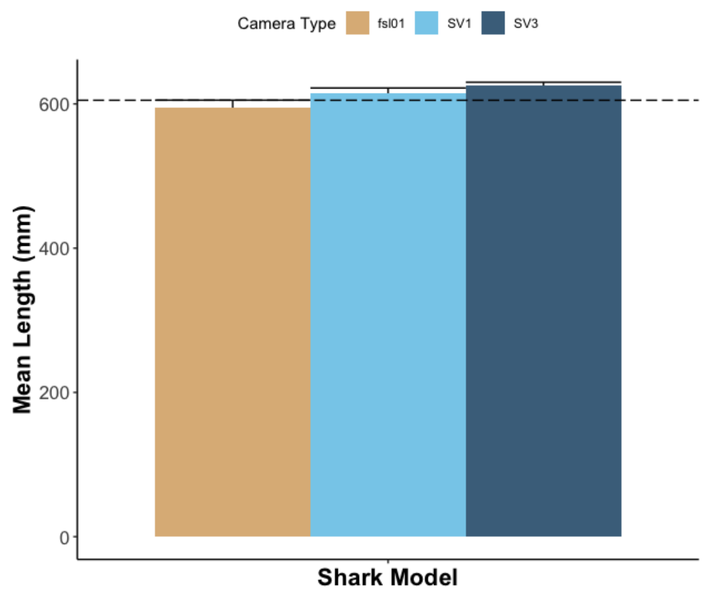

Figure 2. Mean fork length of a model shark (605 mm; dotted horizontal line) measured by a FishSenseLite camera (tan) and stereo-video cameras (blue).

Stereo-video is an accepted, effective means of estimating the size distribution of live fishes *in situ* with a calibrated dual GoPro camera system and videos processed through a SeaGIS EventMeasure software (https://www.seagis.com.au/overview.html) (Stock et al. 2021). However, it is not conducive for use by citizen scientists due to its size and cost. This SMILE pilot study demonstrated the comparability of the FishSenseLite cameras to the existing stereo-video technology (Figures 3, 4, 5).

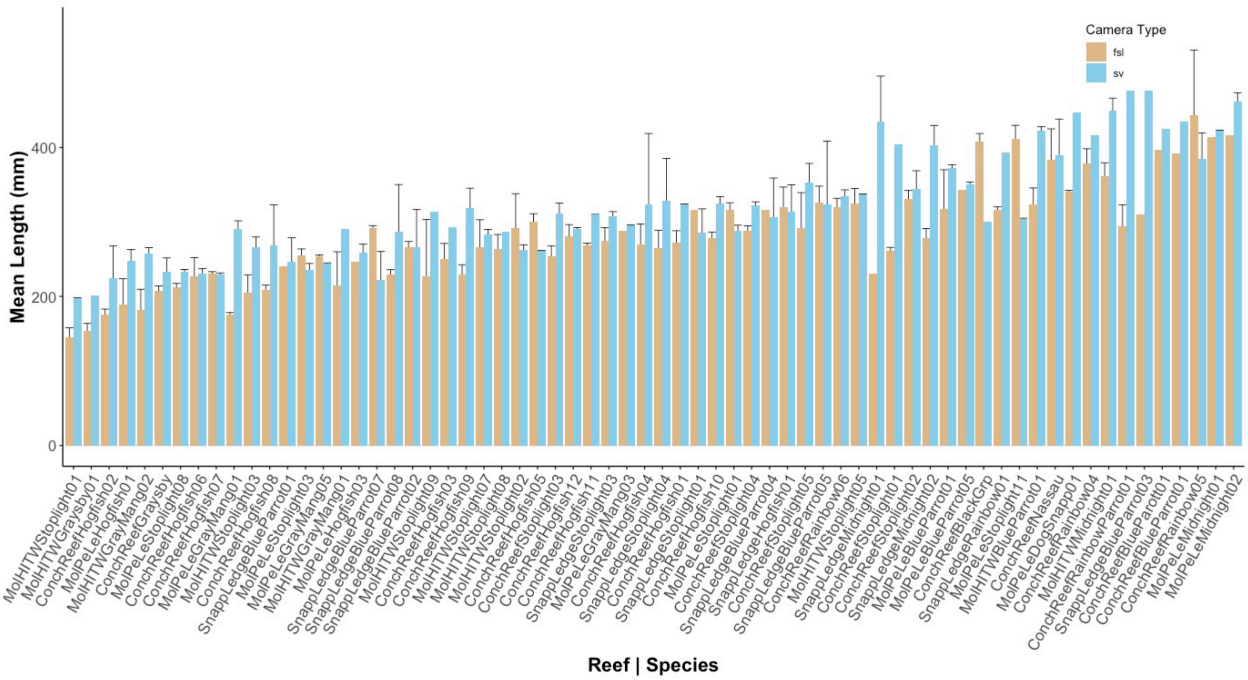

Figure 3. Comparison of mean fork lengths (mm) from the FishSenseLite camera (tan) and stereo-video camera (blue) by individual fish (N=66, x-axis) across four sites in Key Largo, Florida. While the stereo-video system trends marginally higher in fish length estimation, there is no statistical difference by camera system. (Kruskal-Wallis chi-squared = 94, df = 94, p-value = 0.481). Data were collected under NOAA CRCP grant FNA22NMF4410182.

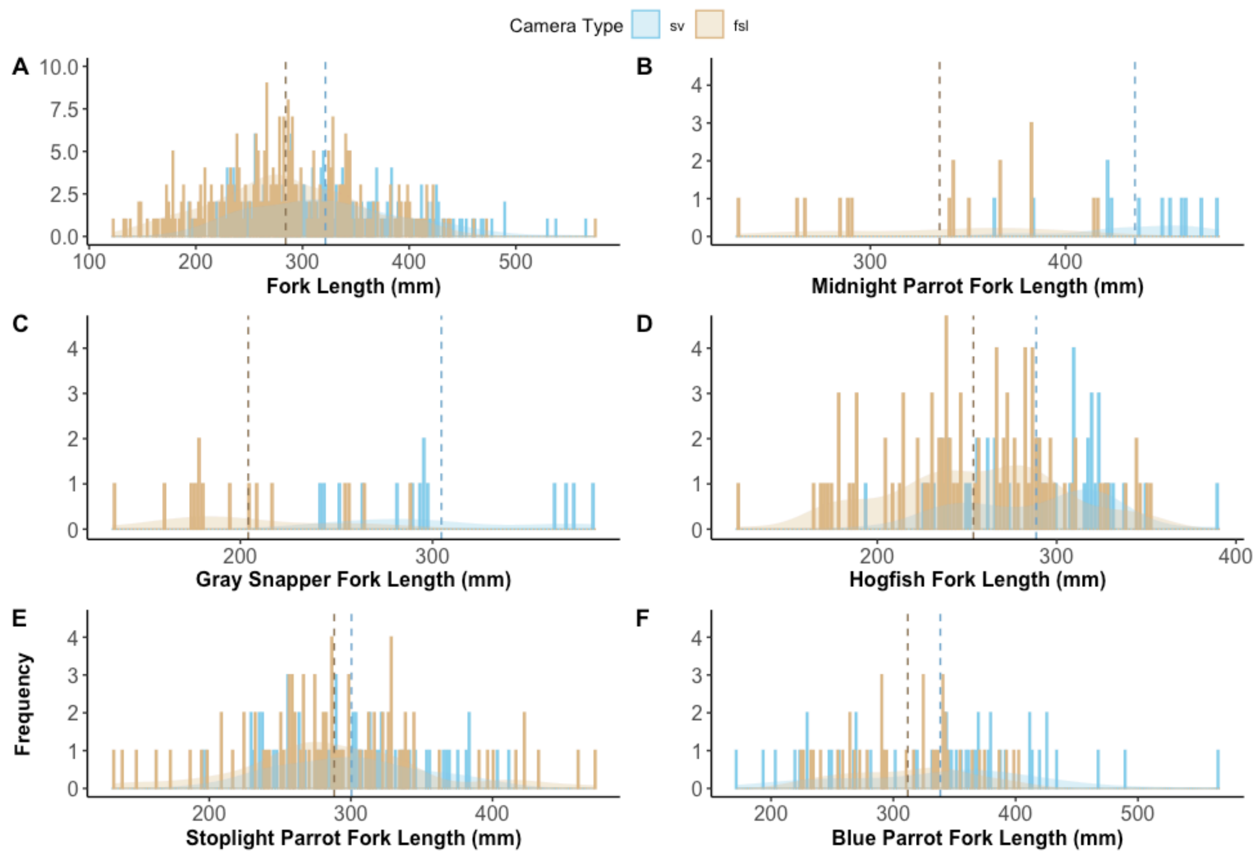

Figure 4. Length (mm, FL) frequency distribution of (A) all fish from Figure 3, and by species: (B) midnight parrotfish (*Scarus coelestinus*), (C) gray/mangrove snapper (*Lutjanus griseus*), (D) Hogfish (*Lachnolaimus maximus*), (E) stoplight parrotfish (*Sparisoma viride*), and (F) blue parrotfish (*Scarus coeruleus*) across four sites in Key Largo, Florida by stereo-video (blue) and the novel FishSenseLite camera (tan) for the SMILE project. Vertical dotted lines represent mean length for each camera system. While the stereo-video system tends to trend toward marginally higher fish lengths, there is no statistical difference in fish lengths by camera system (Kruskal Wallis p=0.481 for all species). These data were collected under NOAA CRCP grant #FNA22NMF4410182, with data processing and analyses ongoing.

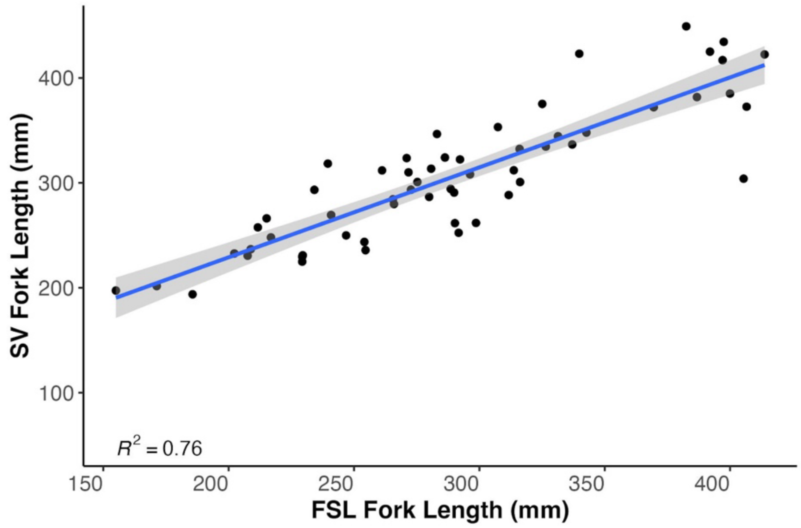

Figure 5. Length (mean mm, FL) regression of individual live fishes paired with both stereo-video and FishSenseLite cameras.

<u>SSC Discussion Questions</u>

Methodology:

- Is the SMILE methodology informative for size data needed for stock assessments and/or management?
  Are there any methodology suggestions or concerns, particularly to boost confidence in this data source?

- How to best handle potential repeat sightings of individual fish?

Data Suggestions:

- Are the selected target species suitable?

- What additional data sources and products would be useful for assessors and managers? (e.g. metadata, citizen science experience)

Data Provision:

- Are there preferences on how to access these data?

- How can we best convey the utility of these data?