Population assessments for target coral reef fisheries species of Guam

Phase I. Data collection and initial summaries

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Project background

While much research has been conducted on Guam's coastal fisheries over the years (Hensley and Sherwood 1993, Amesbury and Hunter-Anderson 2003, Gombos et al. 2007, Houk et al. 2012, Houk et al. 2018), there has been less work dedicated to conducting fish population assessment that can be used to generate species-based management policies. In lieu of species-based policies, marine protected areas (MPA) have been the main focus of fisheries management that provide the broadest protection of coral reef fisheries (Taylor and McIlwain 2010). MPA have proven successful in many instances, however, significant declines in Guam and greater Micronesia nearshore coral reef fish populations have been reported by many studies despite MPA being established for over twenty years (Martin et al. 2016, Houk et al. 2018, Cuetos-Bueno et al. 2019). Evidence has suggested that limited MPA efficacy exists, as published reports over the past decade all suggested MPA have approximately 1.5 times more biomass compared to reference sites when considering the island scale, and MPA have similar biomass compared to the exposed eastern reefs of Guam (Williams et al. 2012, Lindfield et al. 2014, Houk et al. 2022, Taylor et al. 2022). While growing enforcement efforts continue to improve MPA efficacy, MPA cover only <20% of the coral reef habitat on Guam and do not address the remaining reef habitats. Meanwhile, two other primary stressors to Guam fisheries exist in the forms of land-based pollution (Houk et al. 2022) and climate change disturbances (Raymundo et al. 2019). Both appear to have secondary, negative impacts to fisheries resources. In sum, the limited nearshore habitat around Guam coupled with the large and growing human population continue to put a strain on fisheries resources.

In response to growing fisheries concerns, the political leadership of Guam has formed a stronger partnership with the natural resource management agencies. Evidence comes from the recently passed Public Law 35-78 on March 20, 2020, to ban SCUBA-spearfishing that has been a very contentious topic for over 30 years, despite its known threat to viable reef fish populations (Green 2003, Lindfield et al. 2014). While some species-based regulations exist for a few fish and invertebrates, there is a lack of any regulations on catch sizes and amounts for most targeted coral reef fishes. To address this concern, the Guam Division of Aquatic and Wildlife Resources (G-DAWR) requested support from the National Oceanic and Atmospheric Administration (NOAA) Pacific Islands Regional Office to develop a jurisdictional coral reef fisheries management plan for Guam to achieve sustainable fisheries. In collaboration with NOAA Pacific Islands Fisheries Science Center (PIFSC), G-DAWR has been examining life histories of fisheries-targeted species, and recent stock assessments for some of the target species using available data (Nadon 2019). These initial stock assessments were based upon individual fisheries-dependent datasets from the NOAA PIFSC and the G-DAWR. These assessments represented a proof-in-concept for using novel fisheries assessment tools in the ongoing Guam fisheries management planning (FMP) process that has been initiated for coral reef associated fisheries for a subset of species derived from two datasets. The present project expands upon these initial findings and aims to provide higher-resolution assessments using a larger suite of fisheries-dependent and fisheries-independent data from many sources. Using data from many diverse sources will allow for a series of independent examinations for coral reef

fisheries species and help identify their potential need for management based upon numerous indicators of exploitation. The results can be appreciated alongside each other to help stakeholders and resource managers make informed decisions. Each dataset will help to describe how target species may be responding to fishing pressure, and provide both a present assessment and identify the type of management that may be most successful for meeting the biological targets established in the FMP process. These outcomes support sustainable fisheries management options for G-DAWR and fisheries stakeholders to consider in their ongoing coral reef FMP process in 2023. The present phase I report describes each of the datasets that were identified for their potential utility.

Goals and objectives

Here, we propose to first identify species that make up 80% of the catch biomass over the past three decades, and then conduct holistic species-based investigations to identify management strategies that are best suited for each. We consider this akin to a population assessment or a population vulnerability assessment, within which several approaches may be used to evaluate a particular species given the available data. Figure 1 provides an example of top-landed species from one dataset, but we aim to use all available data to generate a priority species list for discussion with stakeholders. We would then conduct species assessments using both visual, catch, and interview data as appropriate. The proposed project framework includes:

1) Define and collect/build/clean all available fisheries dependent and independent datasets for coral reef fishes around Guam with notable sources including:
    a. G-DAWR creel data from the late 1970s to present
    b. Guam long term coral reef monitoring data supported by NOAA through Guam Bureau of Statistics and Planning
    c. Guam long-term coral reef monitoring data from the NOAA Pacific Islands Fisheries Science Center Ecosystem Sciences Division
    d. Independent studies by University of Guam (UOG) researchers/students on fish life history, non-commercial fish landings, MPA assessments, and other investigations of fish assemblages
    e. Other potentially available data such as the NOAA Pacific Islands Fisheries Science Center commercial fisheries bio-sampling program
    f. Fisheries landings across Micronesia (Commonwealth of the Northern Mariana Islands, Federated States of Micronesia, Marshall Islands) that may be used to build a space-for-time examination of fishing pressure using previously published data

2) Examine trends in each priority species using all datasets where sample sizes are sufficient, following a decision tree that takes advantage of the unique structure in each dataset (Phase II, Spring 2023).

3) Build a summary for each species/dataset to come up with management suggestions that best fit the observed population dynamics for each species.

4) Provide the species assessment outcomes to stakeholders working through the Guam FMP process, including outcomes in the FishPath or other tools that may be selected for use.

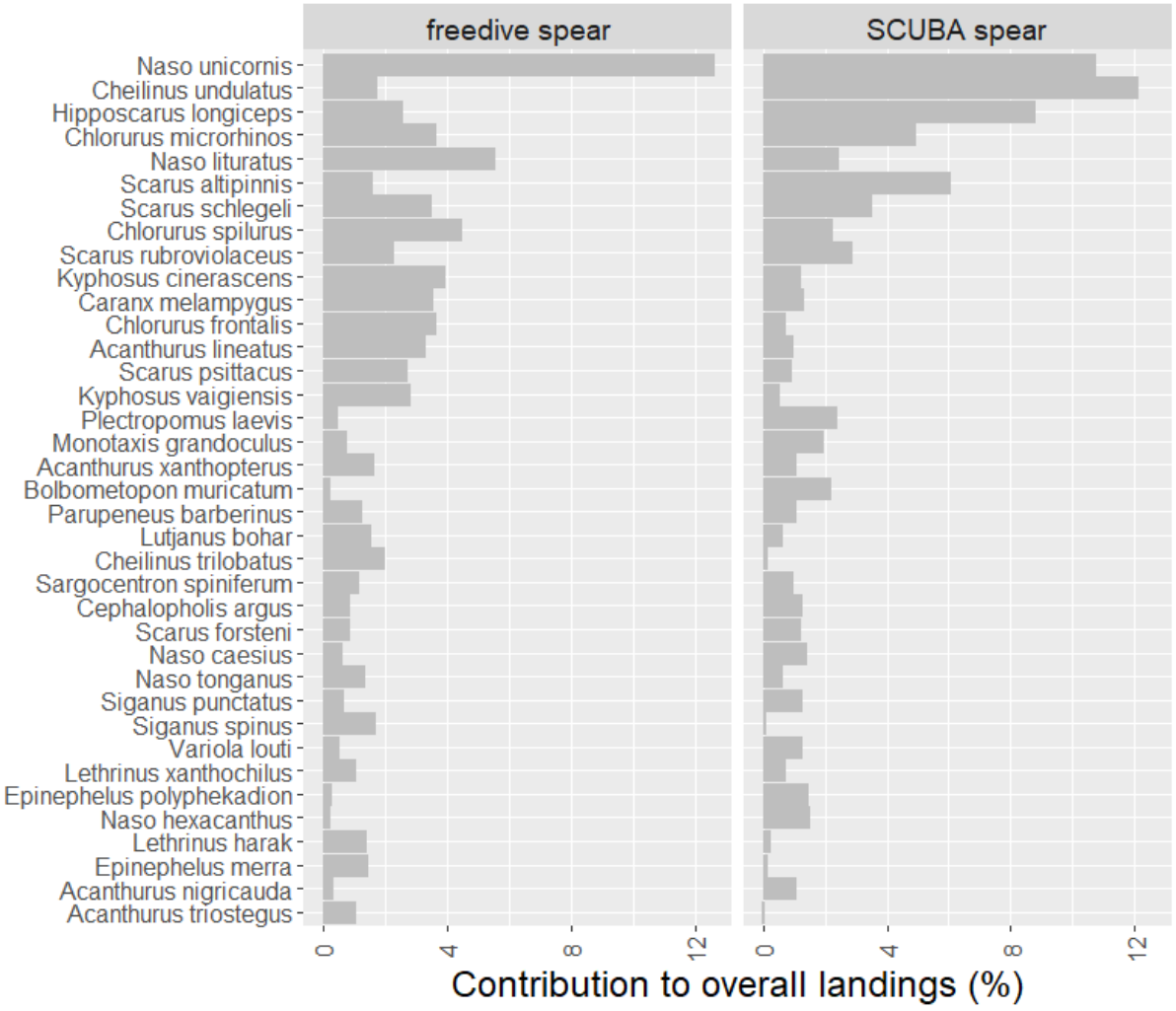

Figure 1. Top landed species in Guam's nearshore spear fisheries derived from the G-DAWR creel data. The present project will generate similar lists from many different data sources and build a collaborative set of priority species for Guam's fisheries management planning process.

The outcomes of this phase I report include integrated, cleaned datasets provided to G-DAWR and stakeholders that serve as the basis for our species assessments. Each dataset is described in detail below, and example graphics have been included to demonstrate the potential utility.

Fisheries datasets

The authors in collaboration with G-DAWR identified a suite of fisheries-dependent and fisheries-independent datasets that could contribute to population assessments. Descriptions of these datasets are the focus of this phase I report. Sources of Guam fisheries data were identified from published studies, grey literature including University of Guam Marine Lab (UOGML) student theses and technical reports, and past and ongoing monitoring efforts by local and federal programs. Each data source was contacted and a request letter originating from the director of G-DAWR was provided alongside the request for data. Data provided were first examined for their structure and format, and any quality control procedures were performed such as corrections to taxonomic nomenclature and format. Next, R-scripts were prepared for each dataset to highlight the utility of each source towards conducting species assessments. Summaries of each dataset are provided below with some graphical outputs. All R-scripts and post-processed data were submitted alongside this report.

1. G-DAWR creel

G-DAWR established a fisheries-dependent monitoring program in 1982 that targeted both commercial and recreational fishers. G-DAWR staff intercept fishers as they return from both boat-based and shore-based trips. Creel surveys followed a regular schedule, including shifts on weekdays, weekends, and evenings when peak fishing periods were noted for each of the fishery sectors (Figure 2). During each survey event, all fish were identified and measured to the nearest millimeter (mm) fork length, and a series of standard questions were asked to determine fishing location(s) and method(s). Species-based data were then entered into a standardized database that is available upon request to G-DAWR. While several sectors were covered by this program, SCUBA spearfishing (down to ~30 meter (m) depth), freedive spearfishing (down to ~18 m depth), gillnets, and shallow bottom fishing (down to ~90 m depth) were most common. The stream of data from this program differs slightly for each fishery, but consistent reporting began in the late-1980s and continues today. Reporting for the SCUBA fishery diminished in the mid-2000s due to controversy among fishers, managers, and stakeholders, however, creel survey effort has remained consistent for other sectors (Figure 3). Most recently, SCUBA fishing has been banned on Guam by PL 35-78 on March 20, 2020.

Proposed species assessments using these data will include: 1) temporal trends in size structure and proportional contribution, 2) using recent length-based data along with life-history data to generate spawning potential ratios and fishing-versus-natural mortality (see below for a description of life history data), and 3) recent proportional contribution data to look at spatial trends across Micronesia using similar data summaries from many islands in Micronesia (see below for a description of Micronesia fisheries-dependent data). Examples of using temporal trends in size structure and proportional contribution can be found in a previous publication that will be expanded upon with data collected during the 2010s and across all priority species identified (Houk et al. 2018).

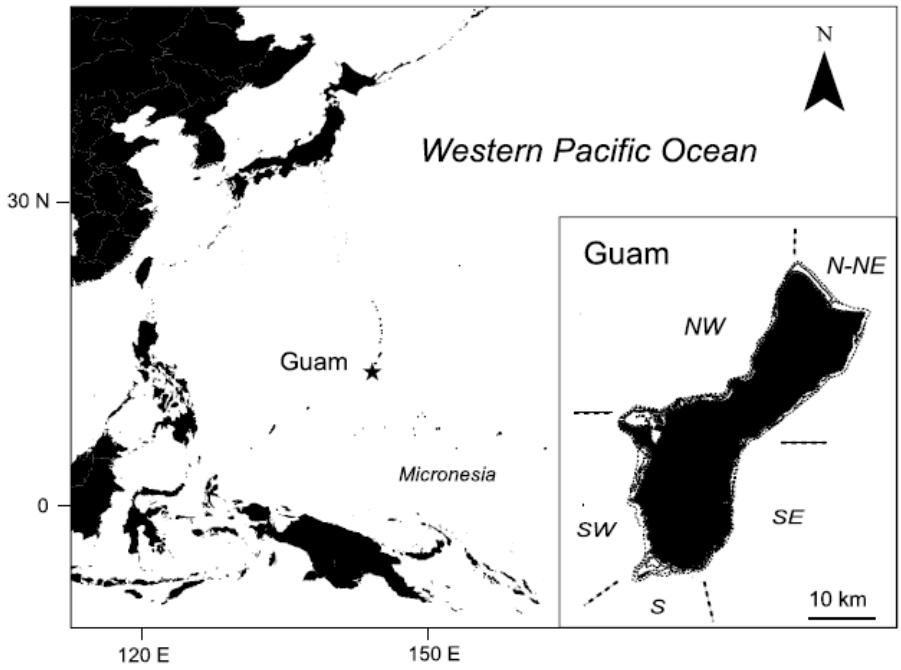

Figure 2. Map of Guam showing the limited amount of nearshore reef habitat (dotted lines surrounding the island). Major geographic fisheries sectors used by G-DAWR are also shown.

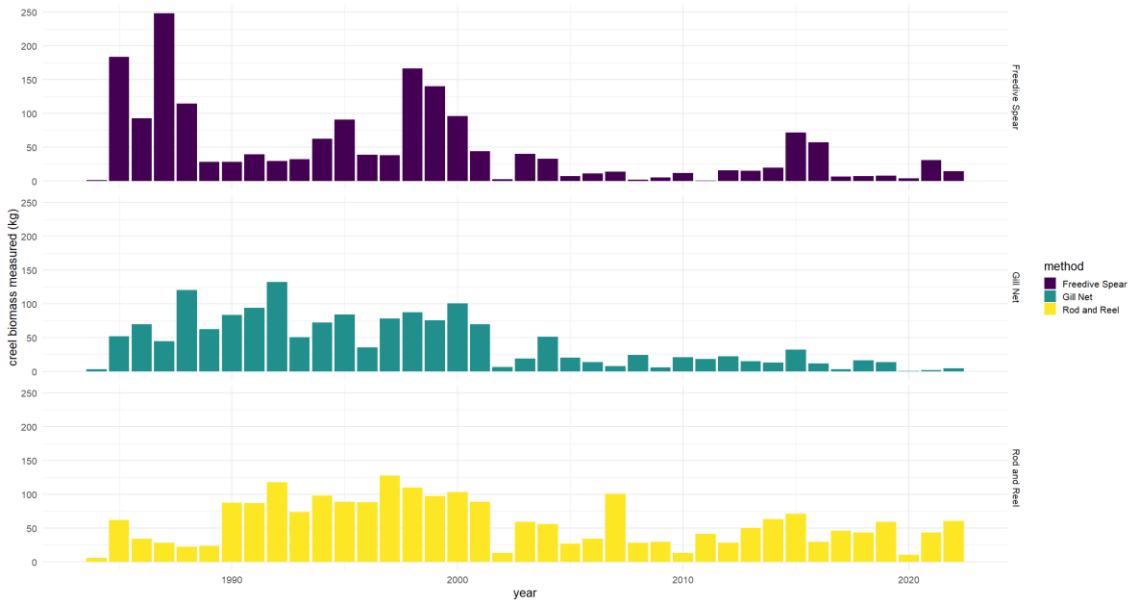

Figure 3. Summary of data collection effort from the G-DAWR creel program for the inshore fishing sector. Boat-based data will also be included in the analyses as they become updated. The y-axis represents the total biomass of creel data measured in kilogram (kg) per year.

2. *Guam ridge-to-reef surveys*

Coral, benthic, and fish assemblage data were collected on reefs adjacent to each watershed during a 2020 to 2022 project conducted by the UOGML and University of Guam Sea Grant (Houk lab, overall principal investigator). The goals were to investigate potential linkages between watersheds, fishing access, and the condition of ecological assemblages as measured from several key metrics of the coral, benthic, and fish assemblages (Houk et al. 2022). These metrics include coral cover, diversity, coral size-class skewness, coral-to-algae ratios, fish size and biomass. All metrics were agreed upon by the regional Micronesia Challenge measures group and selected in combination to account for reef processes essential to recovery and growth (Houk et al. 2015). Survey locations were similarly located at the southern edge of each channel associated with watershed discharge (Figure 4). Five, 50 m transects were laid along the 8–10 m reef slope contour and field protocols followed previous studies designed to address statistical power needs for site-level resolution (Houk and Van Woesik 2013, Houk et al. 2015). Food-fish assemblages were estimated from 12 stationary-point counts (SPC) conducted at ~20 m intervals along the transect lines. During each SPC, the trained observer recorded the species name and the size of all food-fish within a 5-6 m radius for a period of 3 minutes. Food-fish were defined as acanthurids, scarids, serranids, siganids, carangids, labrids, lethrinids, lutjanids, balistids, kyphosids, mullids, holocentrids, and sharks. Fish sizes were converted to biomass using coefficients from regional fishery-dependent data when available (see below), or from FishBase when not available (www.fishbase.org). Ecological data were deposited into the Micronesia Reef Monitoring online database that hosts data, provides data access, and offers collaborations with interested individuals and organizations (https://micronesiareefmonitoring.com/). This project was supported by a grant from the United States Environmental Protection Agency Region IX and is now completed and published (Houk et al. 2022).

Proposed analyses using these data include examining the size structures, biomass, and proportional contributions of priority species across geography (east versus west), fishing access, and MPA status. Proportional contributions for all target species would be calculated for each site. This approach will evaluate the status and responses of target species to fishing access/pressure gradients (Figure 5).

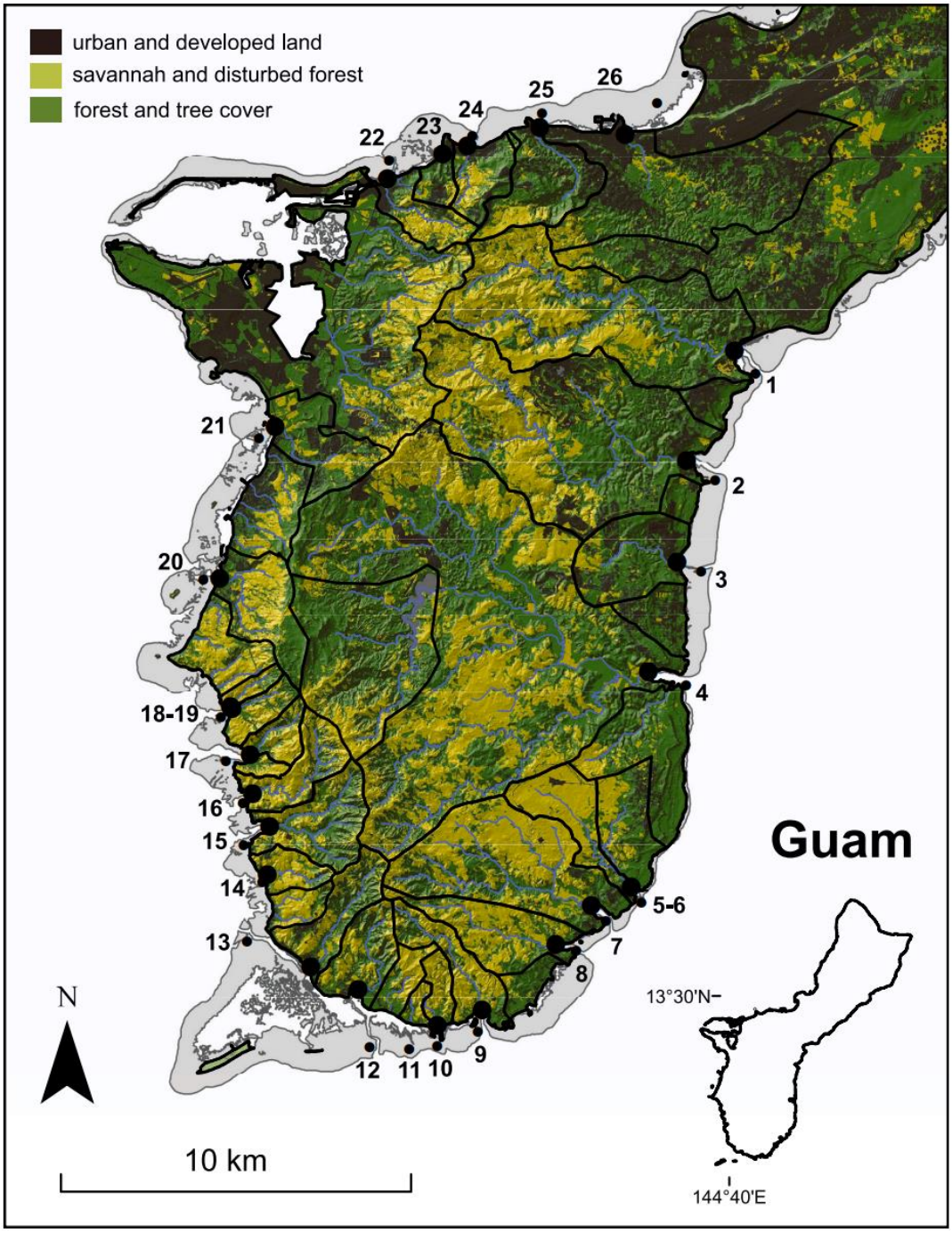

Figure 4. Southern Guam showing the location of survey sites for the ridge-to-reef study where fish assemblages were surveyed.

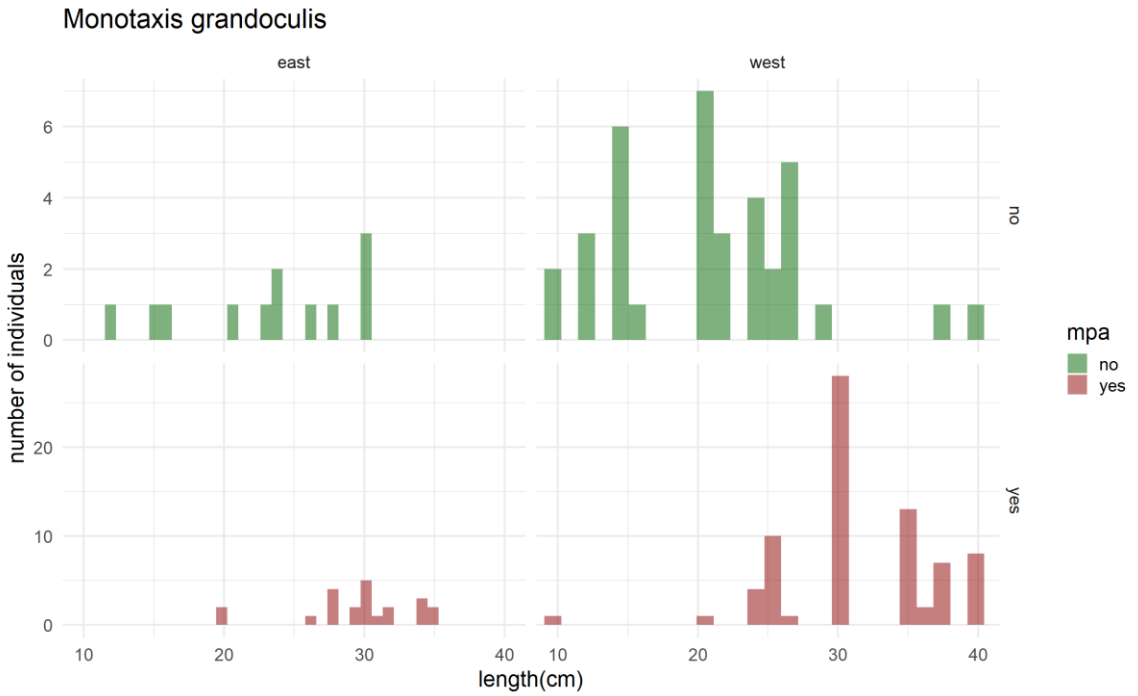

Figure 5. A sample of size data from the ridge-to-reef project summarized for one target species contrasting size structures across geography and MPA status.

3. NOAA Pacific islands National Coral Reef Monitoring Program

NOAA PIFSC Ecosystem Sciences Division conducts a national coral reef monitoring program for all Pacific islands and territories associated with the United States. Sites are selected around each island across major habitats and three depth strata. Major habitats for Guam included geography (west versus east) and MPA (Williams et al. 2012). A series of sites are randomly selected within each strata, with between 30 and over 100 sites selected in individual survey years since 2011. Survey data were available from 2011, 2014, and 2017, with a recent 2021 dataset soon available. All sites were surveyed using a standardized coral reef fish assemblage survey method, stationary point counts (SPC). The SPC protocol involves a pair of divers conducting simultaneous counts in adjacent, visually estimated 15-m-diameter cylindrical plots extending from the substrate to the limits of vertical visibility. Prior to beginning each SPC pair, a 30-m line was laid across the substratum to assist divers conducting surveys and to facilitate benthic data collection. Each survey consisted of two components. The first of these was a 5-minute species enumeration period in which the diver recorded the taxa of all species observed within their cylinder. At the end of the 5-minute period, divers began the tallying portion of the count, in which they systematically worked through their species listing for each species and recorded the number of fish and size (total length, TL, to nearest centimeter (cm)) of each individual fish. The tallying portion was conducted as a series of rapid visual sweeps of the plot, with one species-grouping counted per sweep. To the extent possible, divers remained at the center of their cylinders throughout the count. In cases where a species was observed during the enumeration period but was not present in the cylinder during the tallying period, divers recorded their best estimates of size and number observed in the first encounter

during the enumeration period and marked the data record as 'non-instantaneous.' Surveys were not conducted if horizontal visibility was < 7.5 m, i.e., when observers could not distinguish the edges of their cylinder.

Proposed analyses using these data will be examining trends in size structures and proportional contributions through time at a suite of sites selected to represent a given strata or the island level (Figure 6). Replication was not sufficient to examine MPA comparisons, but note that the Guam long-term monitoring program uses these exact same protocols and is strictly focused on MPA comparisons. So, these two datasets complement each other.

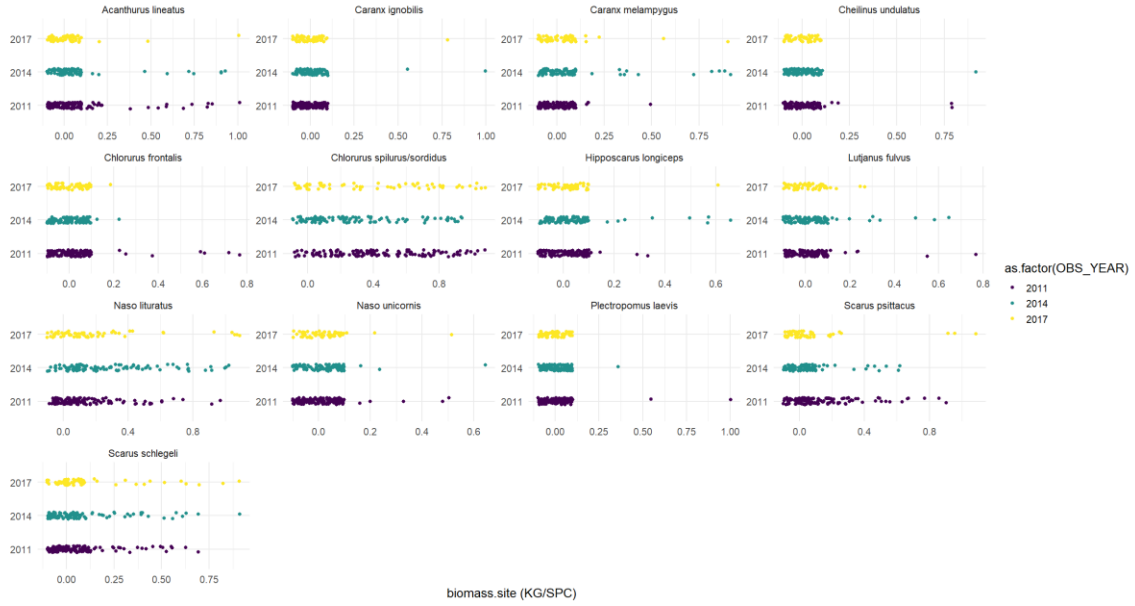

Figure 6. A sample of site-biomass data derived from the NOAA national coral reef monitoring program across several potential target species. See above for methods.

4. Guam long-term monitoring program

The Guam long-term coral reef monitoring program represents a complemental program to the national monitoring program conducted by NOAA PIFSC. The key differences are survey designs as survey protocols are identical. Survey designs are focused on examining MPA efficacy through time and currently focused on Tumon Bay, Piti, and Achang preserves, as well as reference locations. During each survey year, between 20 to 35 sites were established in the MPA and reference locations. This program began in 2010 and currently includes survey data for Tumon (five years), Piti (three years), and Achang (two years). Preliminary investigations revealed that several target species have sufficient presence in the dataset for their assessment (Figure 7). This dataset would be used to compare species biomass, proportional contribution, and size-structure across MPA and through time. Our hope is to identify individual MPA with proven efficacy and then isolate upon the MPA effect statistically to evaluate each species.

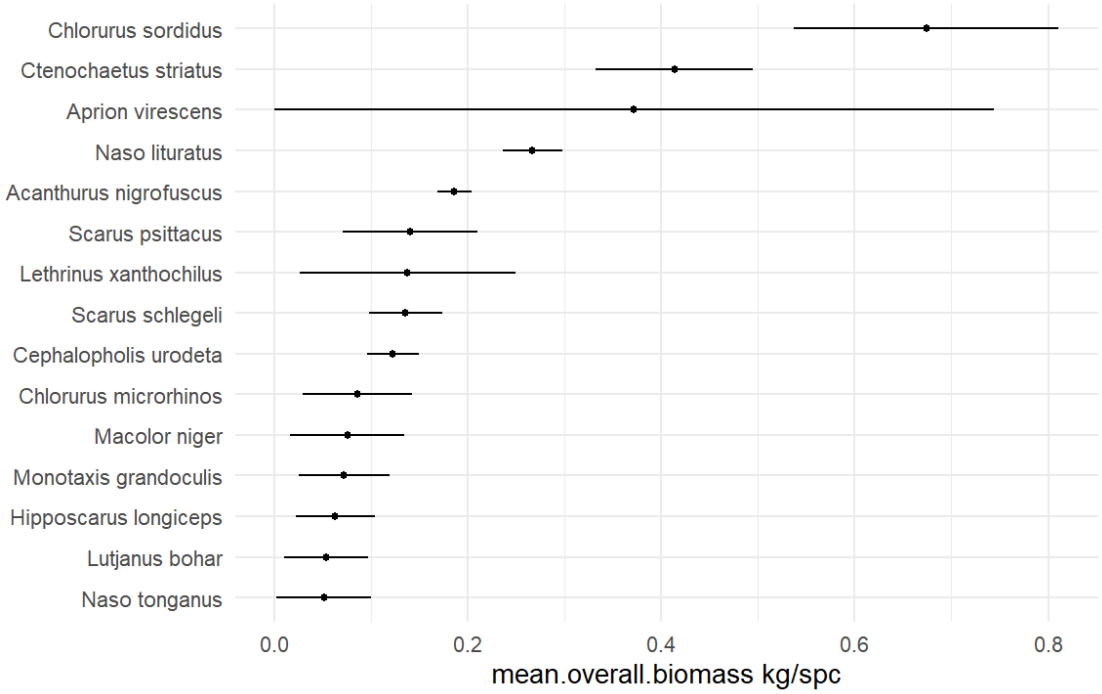

Figure 7. Site-year-averaged biomass for the top recorded species in the Guam long-term monitoring program dataset. This graph provides an indication of which priority species might be assessed using these data.

5. *Stereo-video surveys of Guam parrotfishes*

This dataset was completed by the UOGML with Brett Taylor as the principal investigator. These data represent repeat surveys of parrotfish assemblages on outer reef slopes of Guam during two time periods a decade apart (2011/2012 and 2021) to investigate the effect of fishing pressure, habitat variability, and the two time periods on parrotfish composition, size structure, and ecological function such as grazing potential (Taylor et al. 2015, Taylor et al. 2022). The surveys were conducted using diver-operated stereo video across 17 fixed sites around Guam using 24-minute (2011/12) or 30-minute (2021) timed swims at two depths (6-10 m and 18-20 m) with the distance measured by GPS using a surface buoy, covering an average area of 1.1 hectares per site. Individual fish within 8 m in front and 2.5 m on either side of the camera trajectory were identified down to species level, annotated by color phase (as most parrotfish species have initial and terminal phases broadly associated with sex), and measured to the nearest mm. The 17 sites (Figure 8) span multiple MPAs as well as a wide range of environmental and anthropogenic factors (e.g., exposure, benthic substrate, fishing pressure, adjacent habitats) that are incorporated in the data set. The high amount of survey area at the site level facilitates detailed size structure analysis at the site level for the more common species. The above noted citations refer to past and present uses of this dataset to examine changes in parrotfish biomass, assemblage composition, and size structure associated with gradients of fishing pressure through space and time, and has been used to assess the influence of life-history traits on the intrinsic vulnerability of species to overexploitation.

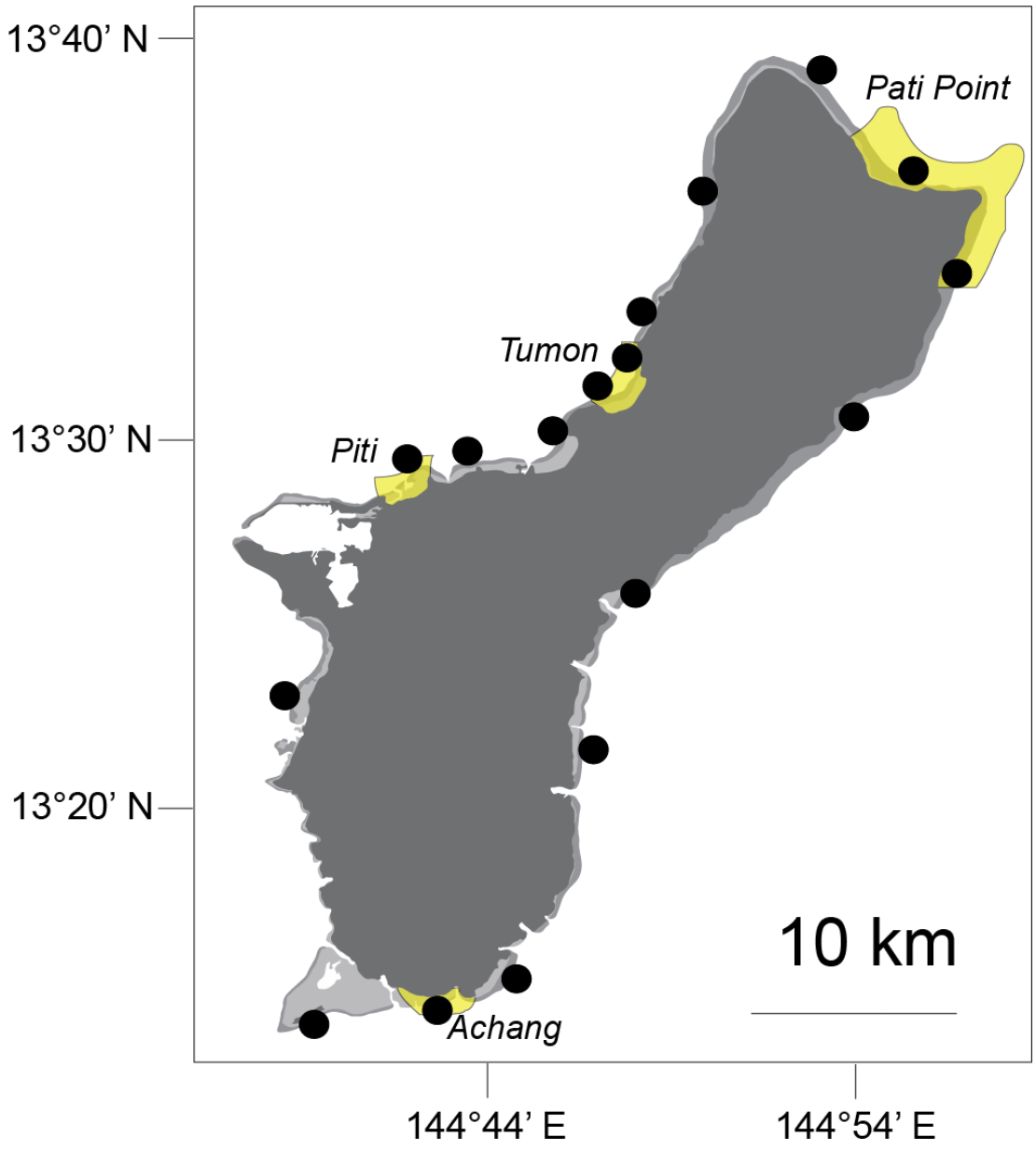

Figure 8. Map of repeat surveys sites on outer reef slopes of Guam where surveys of parrotfishes have been conducted by diver-operated stereo-video. Yellow regions represent marine protected areas incorporated in the survey design.

6. Micronesia fisheries dependent datasets

Fisheries-dependent datasets have been collected over the past eight years from many jurisdictions across Micronesia, including: Guam, Commonwealth of the Northern Mariana Islands (Saipan and Tinian islands), Yap, Pohnpei, Chuuk, Kosrae, the Republic of Palau, and the Republic of the Marshall Islands (Majuro and Arno atolls) (Figure 9). Fisheries-dependent datasets were derived from standardized, intensive sampling efforts across one year, or across major seasons, for all islands. These provided representative

snapshots of the nearshore spear, net, and bottomfish fisheries. Daily visits to prominent fish markets, or visits to prominent fishers, were conducted where fishers were interviewed, and each fish landed was photographed on top of a measuring board. Length data were generated from the photographs, and daily/seasonal trends were examined by coupling length data with fisher interviews. These surveys provided between 30,000 and over 200,000 fish measurements per island-year depending upon the island size. Summaries of island-specific fishery trends and catch data have previously been published and proportional contribution and species skewness data were collected for present use (Houk et al. 2012, Houk et al. 2017, Cuetos-Bueno et al. 2018, Houk et al. 2018, Rhodes et al. 2018, Cuetos-Bueno et al. 2019). Guam data included G-DAWR creel surveys from the past decade as well as size-data from an ongoing UOGML student thesis project that provided a more intensive snapshot of the non-commercial fisheries sector (see below).

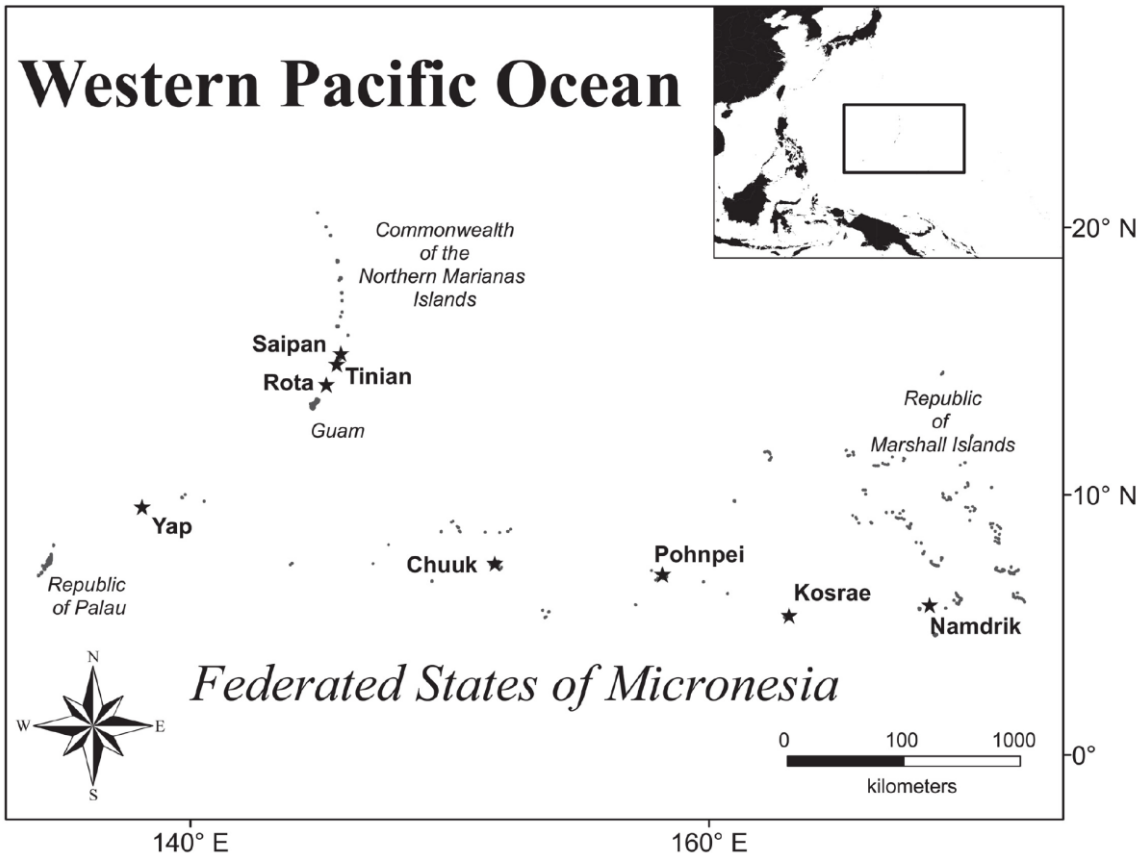

Figure 9. Map of Micronesia showing the islands included in both the fisheries-dependent and fisheries-independent data collection network.

Proposed analyses using these datasets include examinations of size structures and proportional contributions across human population density gradients. Because size-structures are known to shift with local oceanography and island geology, we propose to

use skewness as a comparable metric for population size structures. Human population gradients would be used as a proxy to fishing pressure, and the results will serve to assess the status of target species and the nature of species responses to growing human footprints. Here, we would focus on how Guam fish populations fit into the regional perspective (Figure 10).

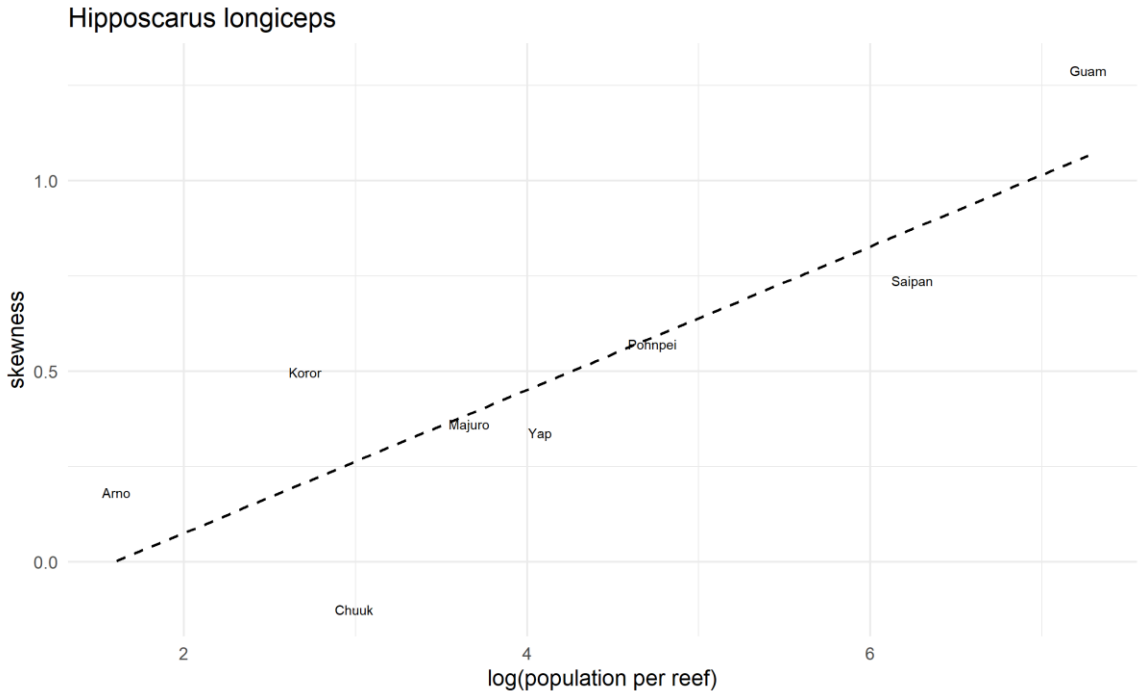

Figure 10. Example of integrating the size-based metric of skewness from fisheries-dependent datasets across Micronesia for one example target species.

7. Micronesia fishery-independent datasets

Fisheries-independent datasets have been collected over the past 10 years from many jurisdictions across Micronesia, including: Guam, Commonwealth of the Northern Mariana Islands (Saipan and Tinian islands), Yap, Pohnpei, Chuuk, Kosrae, the Republic of Palau, and the Republic of the Marshall Islands (Majuro and Arno atolls). Data were collected by many organizations and individuals in a collaborative partnership that defines the Micronesia coral reef and fisheries monitoring network (https://micronesiareefmonitoring.com/). Data from Guam were associated with the ridge-to-reef project noted above and also other ongoing efforts by the same principal investigators. For each island, long-term monitoring site selections were stratified across (i) management regimes, (ii) wave exposure, (iii) islands, and (iv) major reef habitats, to be representative of each island (Houk et al. 2015), with the total number of sites proportional to the area of reef habitat. The sizes and abundances of target food-fishes were collected using standard visual census techniques by experienced and calibrated observers. Food-fish were defined as acanthurids, scarids, serranids, carangids, labrids, lethrinids, lutjanids, balistids, kyphosids, mullids, holocentrids, and sharks. Fish surveys were

conducted using 12 stationary-point counts (SPCs) separated by equal intervals along 5 m x 50 m transect lines established at each site and used for benthic data collection noted below. During each SPC, the observer recorded the species and estimated the size of all fish within a 5 to 6 m circular radius for a period of 3 minutes. Fish sizes were binned into 5 cm categories and converted to biomass using coefficients from regional fishery-dependent data where available (Houk et al. 2012, Cuetos-Bueno et al. 2018, Houk, Cuetos-Bueno et al. 2018), or else from FishBase (www.fishbase.org). Data were deposited into the Micronesia Reef Monitoring online database that hosts data, provides data access, and offers collaborations with interested individuals and organizations (https://micronesiareefmonitoring.com/).

Proposed analyses from this regional dataset would be examinations of proportional contribution across human population densities (Figure 11). Proportional contributions would be calculated for each site-year, and then aggregated to the island scale for comparisons. Size estimates from observers are not as accurate compared to fisheries-dependent datasets described above. Thus, the focus will be on proportional contributions from this regional dataset. Proportional contributions were calculated at the site-year level first, then aggregated to the island-year, then aggregated to the island level to generate a comparable regional dataset across islands. This analysis would serve to understand whether each target species is sensitive to human footprints, and also provide an indicator of the status of Guam fish populations.

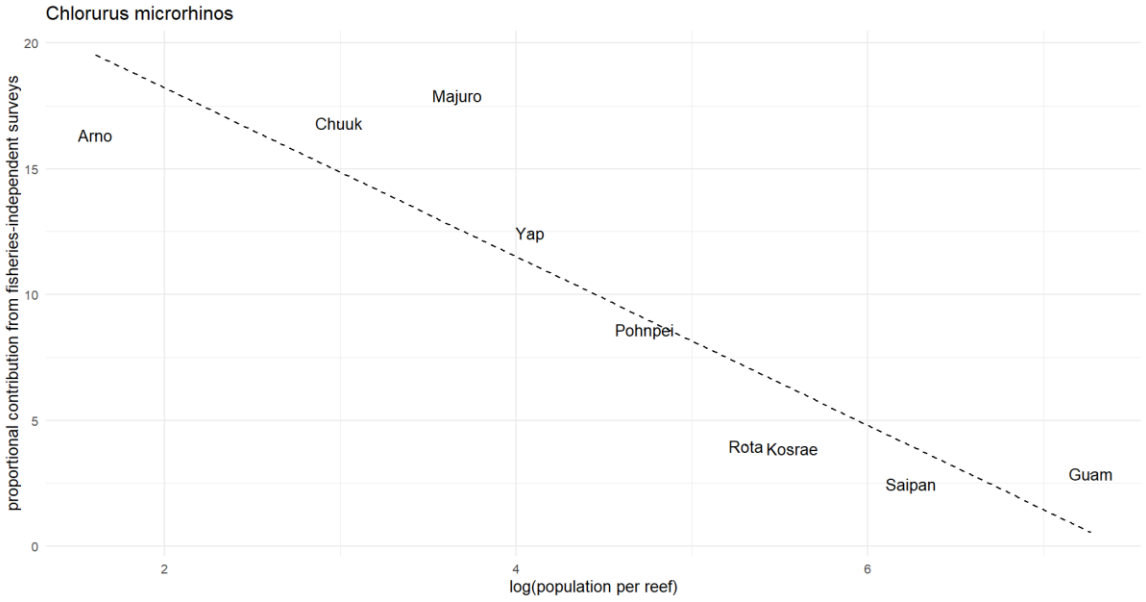

Figure 11. Example examinations of proportional contributions from Micronesia fisheries-independent data for one priority species.

8. *Compiled fish life-history database from Guam and surrounding regions*

Information on the life histories of organisms represents the foundation to population dynamics. Life-history information has often been considered a limiting factor for resource managers in tropical coral reef environments worldwide. However, in recent years Guam and the broader Micronesian region has emerged as an epicenter for information on the life histories of harvested coral reef fish species. As part of this project, we have amassed a dataset of life-history parameter values for 44 species of commercially-harvested reef-associated fishes. Eighty percent of the species data are drawn from life-history studies conducted in Guam or nearby Saipan, Commonwealth of the Northern Mariana Islands, 11% are drawn from the broader Micronesian region, and 9% are from other regions in the Pacific such as American Samoa and Australia with comparable oceanographic conditions. These studies include data from all dominant fishing sectors, including night/day spearfishing, hook-and-line, surround nets, and throw nets. This dataset presents best-fit parameter values of growth (asymptotic length, growth coefficients, size at settlement), natural mortality, life span, length-weight coefficients, reproductive seasonality, size and age at sexual maturity, reproductive contribution relative to body mass, whether or not species exhibit sexually dimorphic growth, and M/K ratios (Prince et al. 2015).

Proposed analyses from this dataset would be (1) to incorporate life-history trait values into population demographic models predicting yield-per recruit, spawner biomass per recruit, recovery potential, or other demographic metrics; (2) to test the level at which the spectrum of trait values (Figure 12) predicts vulnerability to overexploitation within and across families using multiple fishery-dependent and -independent datasets; (3) to investigate the efficacy or influence of different management strategies (e.g., size limits) on the sustainability of species-based harvests; and (4) to provide estimates of fishing mortality (F) relative to natural mortality (M) derived from alternative fishery-dependent and -independent data sets from Guam.

Summary and next steps

The present datasets together provide a novel resource to support the management of coral reef target fishes associated with the freedive, bottomfish, and gillnet fisheries. These fisheries represent the dominant sectors for coral reef habitats, down to 100 m depth. Phase II of the project is expected to begin in January 2023 and continue to May 2023. Phase II will first identify priority target species based upon the datasets compiled during phase I. Subsequently, assessments for each species will be conducted from all available datasets where species presences are sufficient to draw statistical conclusions. Finally, a species table will be provided to summarize findings for their use in the continuing Guam fisheries management planning process currently focused on coral reef fisheries. Any additional datasets provided to G-DAWR to support this process will also be included as we progress into phase II (i.e., NOAA PIFSC biosampling, other student theses, and additions to the present datasets described above). Phase II is expected to result in three deliverables: 1) a technical peer-reviewed paper that will served as a basis of findings for a broader technical audience, 2) a technical report that will summarize findings in greater detail for Guam

agencies and stakeholders, and 3) compelling summaries to describe the benefits of differing management options with presentations that serve to translate the findings to a broader general Guam audience.

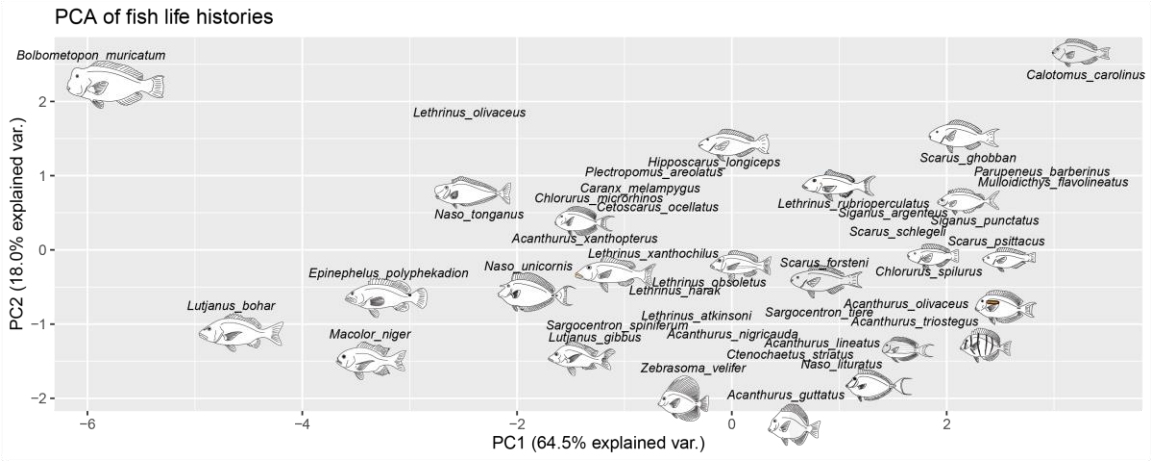

Figure 12. A spectrum of slow to fast life histories across species and families calculated using a principal component analysis of length-based and age-based trait value combinations. Note that the majority of variation (64.5%) is captured within the first principal component, and therefore the life-history spectrum can be simplified to positions along the x-axis. Recovery potential and turnover times should be highly correlated with the first principal component and should thus be a good predictor of species' vulnerability to overexploitation.

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