The Influence of Habitat Complexity on Reef Fish Assemblages

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Abstract

Habitat complexity plays an influential role in coral reef systems in Hawaii. This study looks at different characteristics of the morphological and physical parameters of reef structure to assess its influence on fish abundance, biomass and species richness. To accomplish this, Structure-From-Motion and fish transect surveys were conducted across ten sites on Hawaii Island. Characteristics such as 3D/2D surface area, slope, and benthic terrain roughness were used to classify benthic parameters. Fish data were collected through the Division of Aquatic Resources' annual West Hawaii Aquarium Project using standard belt transect surveys recording fish abundance, size, and species. The results of this study show that fish in West Hawaii target specific 3D morphological and physical characteristics of reef structure in high complexity reef habitats.

Introduction

Benthic structure has a major influence on the assemblage patterns of coral reef fishes (Hixon and Beets 1989). In a study done across Hawaii, complex reef habitat showed robust relationships with reef fish assemblages in the type of habitat, the size of holes in reef structure, and at the depths in which reefs were located (Friedlander and Parrish 1998). Due to the habitat that reefs provide, the existence of largescale, structurally intricate reefs are vital to different types of fish assemblages (Wedding et al 2008). Reef fish assemblages have higher species richness and a higher abundance on reefs with higher complex structure. Different physical categorizations of habitat complexity such as hole size have shown to drive both the biomass and abundance within reef fishes. Areas with mixed hole size showed the highest mix of fish assemblages (Hixon and Beets 1989). Physical features of corals such as branch length exhibited an increase in species richness on reef environments (Komyakova et al 2018). Many of these studies define assemblages of fishes extensively but lack detail on specific physical characteristics of benthic structure. Previous studies of this type have implemented broad characterizations to define benthic habitat by looking at the presence or lack of structural habitat (Komyakova et al 2018, Kufner et al 2007). The use of these broad characterizations of habitats allowed for a general assessment on the fish assemblages in regards to structure or the lack of structure present (Friedlander et al 2007). However, structural influence on reef fish assemblages of specific physical geometric features that coral reefs create is poorly understood.

Structure From Motion (SFM) surveys are currently being used to fill a major gap in the way reefs are looked at, both spatially and physically. The use of 3D models to define spatial scales, coral colony spatial patterns, and physical characteristics of habitat complexity have shown new ecological incites of reef ecology. A study done by Burns et al (2015) looked at significant differences in physical 3D characteristics of corals in the northwestern Hawaiian Islands. These unique and quantifiable parameters have provided further interpretation of habitat complexity. Spatial analyst tools such as GIS have allowed for further examination of 3D structure (Walbridge et al 2018). In a study done by Fukunaga et al (2019), spatial analysis tools were used to determine and define habitat characteristics. Various measures were defined including 3D surface area, slope, vector ruggedness measure (VRM), curvature, surface to planar ratio, and viewshed distance. Each of these habitat complexity characteristics expressed and defined specific key metrics of the structural complexity of reefs.

The West Hawaii Division of Aquatic resources (DAR) has a network of permanent sites stretching the length of the West Hawaii. These sites are used for the annual West Hawaii Aquarium Project (WHAP) surveys. This study focuses on 10 of the West Hawaii sites that are evenly distributed along the coastline to assess habitat complexity and its impact of on reef fish assembleges. The goal of this study is to look at how key charicteristics of benthic habitat complexity impacts species richness, abundance, and biomass. Three different physical features were used to measure habitat structure: 3D surface area, slope, and vector ruggendess measure. Results from this study will assist in future mangament and different assessments of reef structure. Determining what structual factors that drive primary fish assembleges will assist in defining assemblege patterns of Hawaii's reef fishes .

Materials and Methods

Site Characterization

The present study took place on the west coast of Hawaii island, Hawaii, USA. This fringe-reef coastal ecosystem ranges in depth from 8 m - 18 m and sites vary in proximity to major physical anthropogenic influences. These sites are part of an ongoing study by the Division of Aquatic Resources and are maintained and resurveyed annually (Figure 2). Data collection took place in two parts. Fish surveys were conducted once every other month at each site from May 2018 through November 2018. SFM surveys were conducted once at each site from May 2018 through August 2018. Ocean conditions, including surf and tides, varied between sampling days.

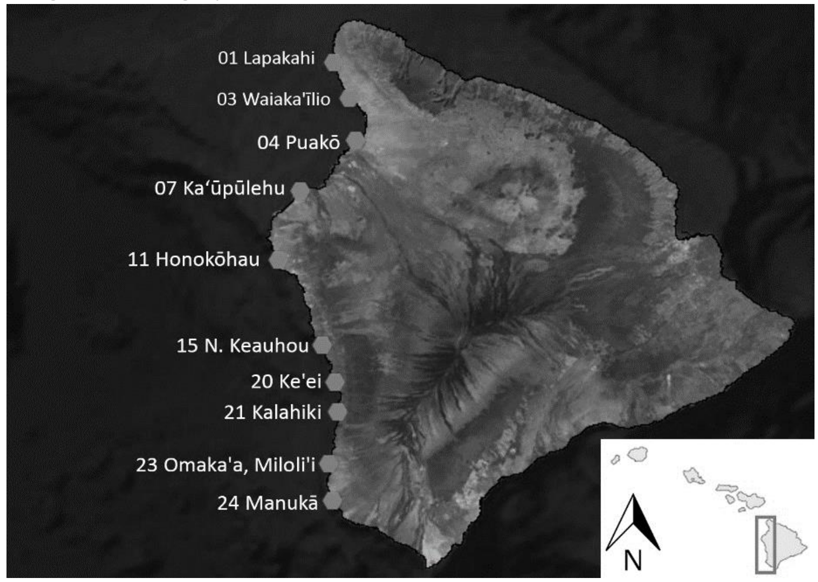

Figure 1. Map of survey station West Hawaii and coastline in Hawaii, U.S.A. A total of ten survey stations at fixed sites that were distributed across west Hawaii.

Assessment of Benthic Composition

SFM photogrammetry surveys were used to calculate structural composition at each survey site. Surveyors placed Ground Control Points and reflective articulated triangulators on the outside corners of each of the four 4 m x 25 m survey plot in order to designate the boundaries of the survey area. The SFM surveyor swam in a boustrophedonic pattern over the survey area while taking continuous photos, ensuring 60-80% overlap of the images (Burns et al. 2015). Images were taken with a Canon 5D Mark IV using a 16-35 mm lens (Canon U.S.A., Inc Melville, New York, USA) with an Ikelite housing that has an 8 inch hemispheric dome port (Ikelite Underwater Systems, Indianapolis, Indiana, USA), reducing refraction and ensuring high quality images. Images were uploaded into PhotoScan modeling software (v1.4.4, Agisoft LLC., St. Petersburg, Russia). 3D model generation was conducted using the methods in Burns et al. (2015). Digital Elevation Models (DEM) and orthomosaics were built and exported out of Agisoft to be used for data extraction in ArcMap.

Orthomosaics were imported into ArcMap, where 9 spatially rectified 3 m x 3 m survey plot raster data sets were digitized onto the surface of the orthomosaic. 3D surface complexity was calculated using Surface information tools (Burns et al. 2015). ArcMap extension Benthic Terrain Modeler was used to convert the base DEM to slope and vector terrain

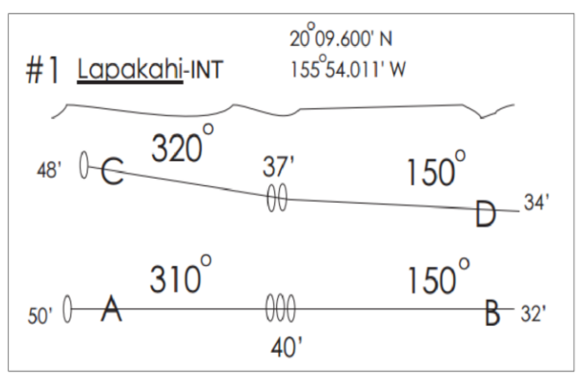

Figure 2. Site map of individual survey station. Four transects secured by pins mounted into the reef.

ruggedness rasters to calculate mean slope, and vector ruggedness measure (Walbridge et al 2018).

Reef Fish Assemblages

Four divers in dive teams of two lined up approximately 5 m from the center pin and begin the survey of each of the 25 m transects. During the first portion of the survey a high swim was conducted 3 m above the benthos, each pair of divers swam down the transect line and recorded species and size larger mobile fishes transiting the line and mid-water species. During the second portion of the survey, the low swim, the diver pair turned around at the end pin and slowly swam back along the transect line toward the center pin (Figure 2). Fish that were counted on the high swim were not counted again on the low swim. Fish were recorded by species and size class. The size of each fish recorded reflects total length (TL), or the length from the tip of the snout to the longer lobe of the caudal fin.

Statistical Analysis

Linear models were conducted to assess the relationship between Biomass, surface complexity, VRM, and slope. Linear models were additionally used to assess abundance and species richness relationship with surface complexity, VRM, and slope. All statistical analysis took place in R studio.

Results

Analysis across west Hawaii showed relationships and positive trends between reef fish assemblages and structural complexity. Surface area had positive relationships with biomass and abundance but did not have any relationship to species richness (Figure 3). Surface area varied across sites and transects with site averages ranging from 15.01 – 22.10 m^2(Table 1). Slope had positive relationships equivalent to surface area. Slope had positive relationships with biomass and abundance, while having no relationship to species richness. Average slope ranged among sites from 29.79 degrees – 48.23 degrees. Vector ruggedness measure had a positive relationship with abundance but showed no relationship between biomass or species richness. VRM ranged across sites from 0.02 – 0.10 (table 1).

Table 1. Average surface area, vector ruggedness measure, slope, species richness, abundance, and biomass are categorized by survey station. All data collection took place between May of 2018 through November of 2018 at the West side of Hawaii island, HI, USA.

Survey Station	Surface Area	Vector Ruggedness Measure	Slope	Species Richness	Abundance/m^2	Biomass/m^2
1	15.01382	0.029502185	29.7928	24.7	1.6	29.74183
3	19.20849	0.062622639	41.8479	23.5	1.9	79.06802
4	21.22624	0.075823972	43.2849	28.1	2.5	224.6263
7	17.06109	0.048243278	38.9324	21.3	1.8	82.76906
15	21.28033	0.095697778	44.5965	16.3	1.1	39.95465
20	20.21769	0.081726028	44.0864	20.8	1.9	83.60418
21	22.10405	0.102871222	48.2321	25.3	2.9	100.3582
23	18.98956	0.081415611	42.8385	26.1	2.8	83.92799
24	20.32958	0.082106889	46.3795	31.6	4.4	149.2679

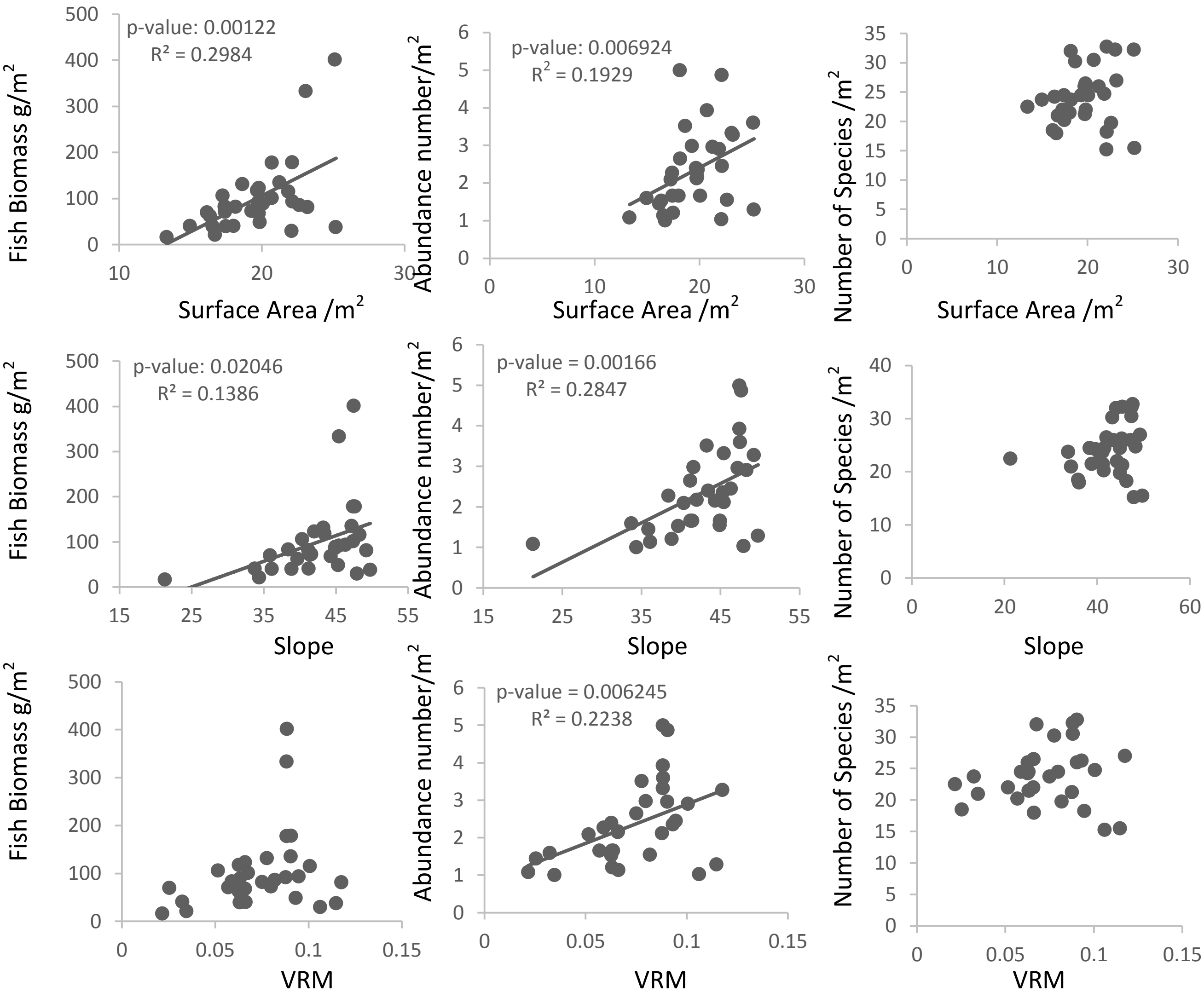

Figure 3. Linear models examining the relationship between biomass, abundance, species richness and surface area, slope and Vector Ruggedness Measure.

Discussion

The results from the study showed structural complexity is a key driver in reef fish assemblages in west Hawaii. Specific descriptions of this complexity such as the vertical relief, change in terrain, and area of structure play diverse roles in driving assemblage patterns. Reef ecosystems with higher structural complexity have up to three times higher fishery productivity than those without (Rodgers et al 2014). This study shows similar results to a variety of other studies in that complex hard structure drastically increases assemblages of reef fishes (Bellwod and Hughes 2001, Freidlander et all 2003, Hixon and Beets 1989). The distinct complexity characteristics within this study demonstrate a relationship between larger and a higher abundance of fishes targeting specific geometric types of reefs complexity.

A positive relationship between fish biomass and fish abundance with reef surface area showed that west Hawaii reefs show a similar trend to other reefs around the state (Figure 3). When physical structure on a reef has more surface area per 2D unit area it drives an increase in the abundance and biomass of fishes. This result matched with other studies in Hawaii confirming the importance of hard substrate for higher biomass and higher abundance. While this study focused on physical abiotic characteristics of reef benthic complexity, further analysis would be needed to assess the impacts of areas with higher coral surface area on fish assemblages. A study done by Burns et al (2015) showed specific differences in Hawaiian coral surface area complexity (Burns et al 2015). These variances in coral surface area to other benthic area could play a key role in driving fish assemblages. Structure and extent of these reefs play a major role in the capacity of fishes that reefs maintain (Bellwood and Hughes 2001). A variety of other influences such as wave and surge motion, depth, and proximity to deeper habitat could also be influencing the assemblage pattern that occur in west Hawaii (Freidlander et al 2003).

Vertical relief, or slope of benthic structure played an influential role on fish assemblages increasing both biomass and abundance. And increase in geometric slope on reef benthos is a resuld of vertical rise on the reef substrate. Higher slope is associated with drop offs and ledges as well as corals with high surface area and low basal plates (Burns et al 2015, Burns et al 2019). Coral such as *Porites compressa* and large *Porites lobata* have steep sloping sides that give benthic structure higher slope values (Burns et al 2015). A dramatic increase in slope on benthic surfaces leads to higher biomass and abundance in the assemblages. The slope results from this study show a similar trend to a study done by Walker et all 2009) who looked at reef elevation change and saw positive changes in reef elevation change and fish abundance. Alternatively, to this study Walker et al (2009) found that elevation change increases species richness.

Differences in terrain changes showed a relationship in the abundance of fishes. Using the VRM, benthic structure changes in 3 cell neighborhood sizes confirmed a positive trend in the driving fish abundance. This specific measure of benthos wide terrain change shows how larger amounts of fish are inhabiting reefs that are more different across the substrate instead of uniform substrate. This relationship between abundance in turn to biomass may be caused by small abundant schooling fish such as fish such *Chromis* and small Juvenile fishes. These small and schooling fishes congregate feeding in the water column and then often dart back into complex reef structure. These fish are higher in abundance but provide small biomass metrics.

Unlike previous research, the results from this study showed no relationship between the species richness of fishes to any of the complexity variables. One of the reasons why there may not be a relationship is the depth in which this study was conducted. Each transect was conducted in a 10 m isobath in similar types of reef environments. A study done by Friedlander and Parish found differences in diversity across depths and reef structures. Reef fishes in this study may show no relationship between species richness due to the lack of depth strata between sites and transects. Each site may have the same species but in different assemblages of biomass and abundance. Further investigation into the effects of other factors such as coral cover and intra species interaction is needed to determine further relationships to species richness and complexity characteristics.

The importance of understanding and effectively quantifying both structural complexity and reef fish assemblages is essential for managing fish populations in intricate reef environments. The presence of high complexity on reefs is essential to healthy reef fish assemblages. The decline of this complexity can have dramatic effects on the reef fishes causing a decrease in productivity by nearly threefold (Rodgers et al 2014). Reefs nonliving structure will still boast higher reef fish assemblages however, when this structure degrades over time the fish assemblages will too (Rodgers et al 2017). The results from this study show that specific physical characteristics of habitat complexity's influence on higher levels of fish abundance and fish biomass. However, as reefs degrade over time due to anthropogenically caused stressors, these characteristics may no longer provide the necessary habitat needed for proper fish assemblage structure.

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