SPECIES DIVERSITY AMONG MARINE CAVES IN BERMUDA

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Abstract Complex habitat structures have proven to be ideal locations for a variety of species seeking protection and shelter. Marine caves formed from corals and rocks provide a complex habitat for protection for fish hiding from predators and other potential threats. Shallow coral reef areas in four bays (Harrington Sound, Tobacco Bay, Shelly Bay, and Whalebone Bay) in Bermuda were surveyed for marine caves to analyze associations between cave size and species diversity, as well as to observe possible relationships among various reef fish species. Video footage was taken of each cave to document the abundance of resident fish. The height of each cave was measured at every location, yet the length of each cave was measured only at Shelly Bay and Whalebone Bay. Negative associations were found between species diversity and both cave height and area. A negative association was also found between total fish number and cave height, but a positive association was found between total fish number and cave area. The most abundant reef fish species found across the four bays' caves were the *Holocentrus* species (squirrelfish) and *Haemulon flavolineatum* (French grunt).

Key Words: *habitat complexity, species diversity, reef fish*

Introduction

The level of complexity in a habitat is a significant influence in determining population dynamics, such as species abundance and diversity (Almany 2004). Habitat complexity provides a method for organisms to increase the level of protective capacity and minimize the effects of predation and competition. For marine organisms, specifically fish dwelling around coral reefs, a prime shelter could be a crevice or cave. Choice of habitat can be the primary factor in determining survival of prey; a study on juvenile damselfish species and predation showed that juvenile survival rates increased significantly in more complex habitats, and that the effects of predation were clearly dependent on habitat selection (Beukers and Jones 1997).

The broad focus of this experiment was to investigate the diversity of fish species in marine caves. However, the results of this study will ideally be able to touch upon many specific questions pertaining to population dynamics in Bermuda bays, including: whether one species is dominant in marine caves; whether certain species dwell together; and whether the size of the cave determines the number of fish or species dwelling inside. Hypotheses from previous literature on similar topics are relatively vague, so this research can improve upon preceding research (Hixon 1998).

Materials and Methods

The study site consisted of thirty-nine caves among four shallow bays in eastern Bermuda: Harrington Sound, Tobacco Bay, Shelly Bay, and Whalebone Bay. Species of interest included all reef fish found in these locations; a complete list of species identified among the study sites is provided in Table 1. The caves investigated in this experiment were found haphazardly.

Table 1; A complete list of all identified animals for each study site. Tobacco Bay had 1 unidentifiable fish among its caves, and Whalebone Bay had 4 unidentifiable fish among its caves; fish were unidentifiable due to quality of film, lighting, and/or distance from camera.

Harrington Sound	Tobacco Bay	Shelly Bay	Whalebone Bay
French Grunt	Yellow-tailed Damselfish	French Grunt	Blue-striped Grunt
Four-eyed Butterflyfish	J. Cocoa Damselfish	Ocean Surgeonfish	French Grunt
Ceaser Grunt	Four-eyed Butterflyfish	Sergeant Major	Blue Tang
	Squirrelfish	Four-eyed Butterflyfish	Squirrelfish
	Blue Angelfish	Longspine Squirrelfish	Reef Squirrelfish
	Goatfish	Spiny Lobster	J. Slippery Dick
	Sergeant Major	Silver Snapper	Four-eyed Butterflyfish
	J. Blue Tang	Yellow-headed Wrasse	J. Stoplight Parrotfish
	Slippery Dick	Squirrelfish	Spotted Sea Cucumber
	Blue-striped Grunt	Soldierfish	Goatfish
	Ocean Surgeonfish		Ocean Surgeonfish
	Blue Tang		Bicolar Damselfish
	Grey Snapper		Sand Diver
	Bleney		Bermuda Bream
	Bermuda Bream		J. Cocoa Damselfish
			Rainbow Parrotfish
			Cocoa Damselfish
			Blue Angelfish
			Slippery Dick

Both the outside and inside of caves were recorded using one of three video cameras (Harrington Sound and Tobacco Bay - Flip Video; Shelly Bay - GoPro; Whalebone Bay - Kodak Play Sport); this method is parallel to that used by Bussotti et al. (2005) in a similar study assessing marine cave diversity off the Salento Peninsula, Italy. Caution was taken when approaching and recording caves as to avoid scaring organisms away from the site. A meter stick was then used to measure the heights of caves (from bottom of cave opening to top of cave opening) at Harrington Sound and Tobacco Bay and the heights and lengths of caves at Shelly Bay and Whalebone Bay. Videos and Humann's *Snorkeling Guide to Marine Life* (1995) publication were used to identify reef fish.

Results and Discussion

No significant association was found between cave height and species diversity ($r= -0.23$, $t_{df=37}= -1.43$, $p= 0.16$) and between cave area and species diversity ($r= -0.17$, $t_{df=18}= -1.07$, $p=0.30$) (Fig. 1); for both of these, the results suggest that a larger sample might have produced evidence for a negative relationship. If so, a smaller cave would provide a more inconspicuous location for reef fish to avoid predators, resulting in greater species diversity among smaller caves.

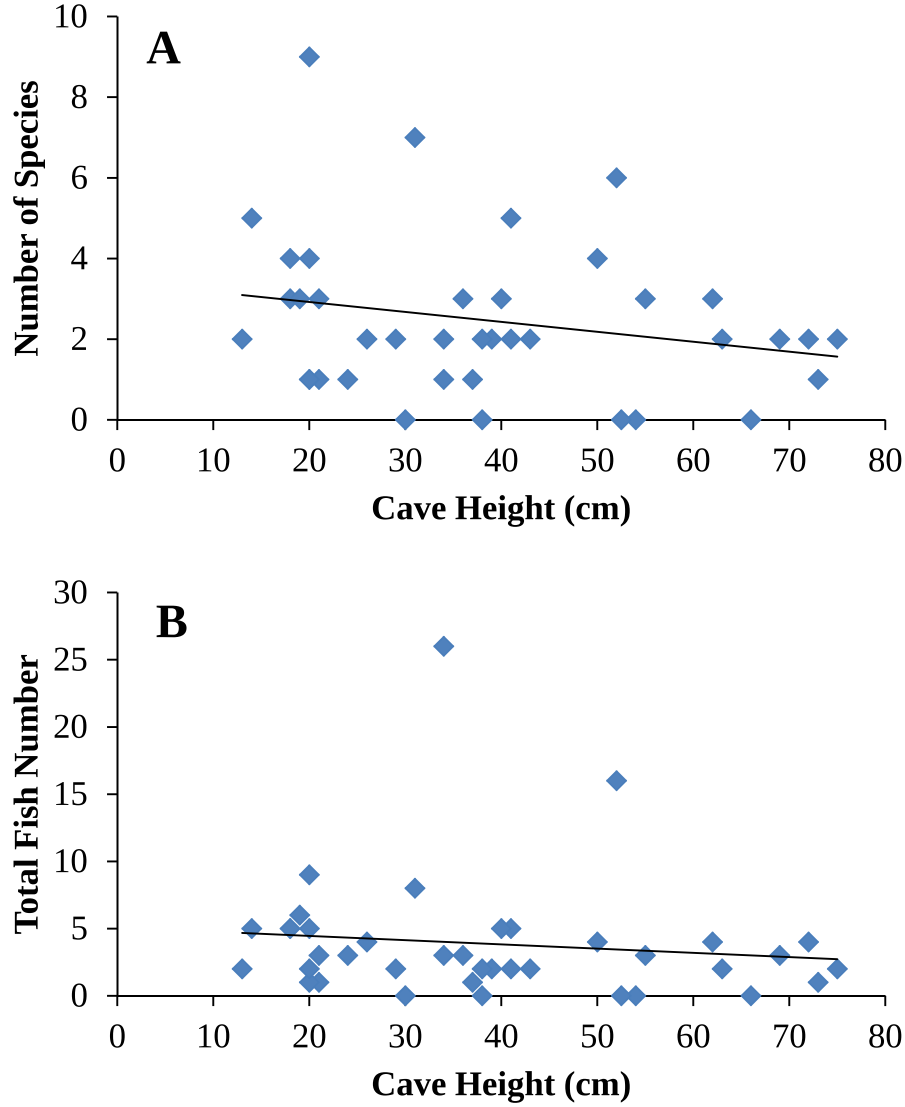

Figure 1; Number of species (A) and number of total fish (B) as a function of cave height. Data is from all four locations (Harrington Sound, Tobacco Bay, Shelly Bay, Whalebone Bay). Negative associations were found for both number of species (A) and total fish (B) regarding cave height; a smaller cave height associates with greater diversity and fish abundance.

Negative associations were found between cave height and total fish number (r= -0.12, $t_{df=37}$= -1.06, p= 0.29) but a positive association was found between cave area and total fish number (r= 0.15, $t_{df=18}$= 0.97, p= 0.34) (Fig. 2); both associations were found to be non-significant with p-values of 0.29 and 0.35, respectively. Though larger caves sustain fewer species, greater general fish abundances were found in smaller caves.

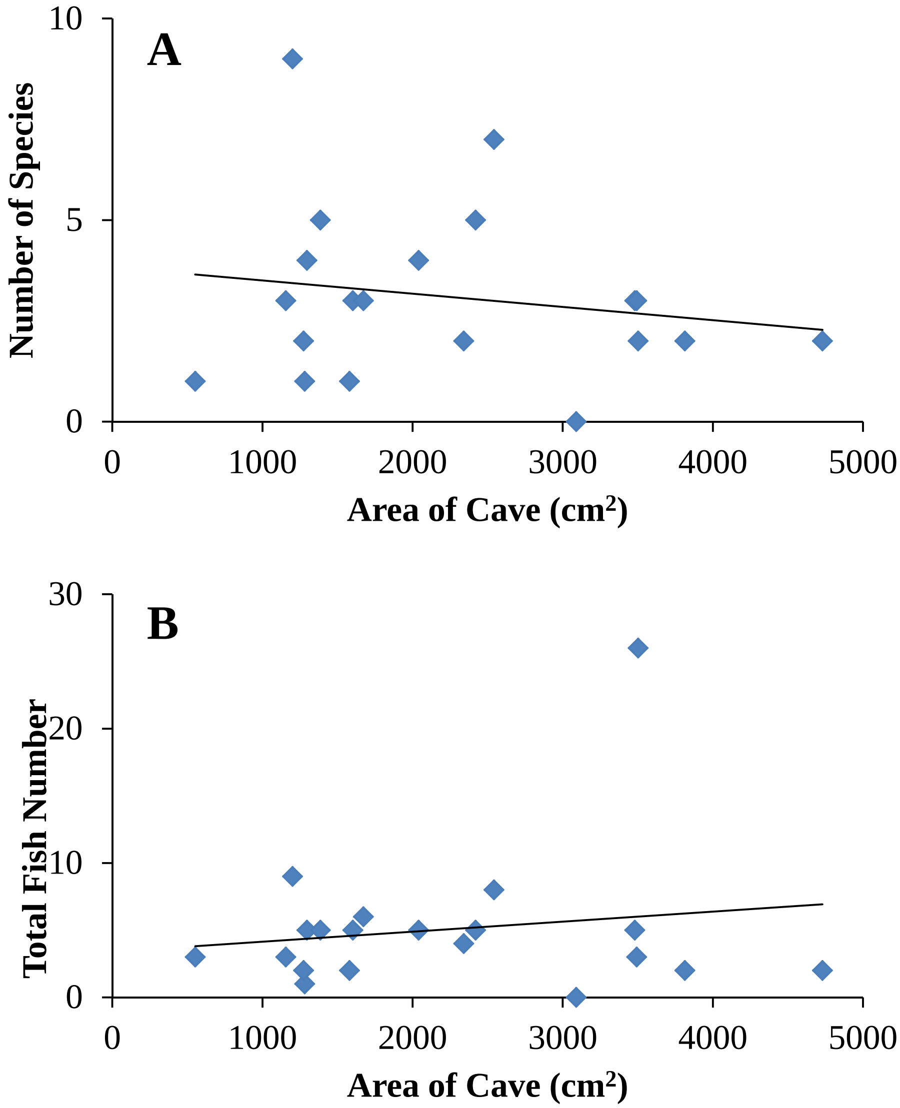

Figure 2; Number of species (A) and number of total fish (B) as a function of cave area. Data is from two of the locations (Shelly Bay and Whalebone Bay). Unexpectedly, a negative association was found between number of species and area of cave (A), whereas a positive association was found between number of total fish and area of cave; this shows that larger caves sustain higher abundances of fewer species.

The five most abundant species found across the 39 marine caves, in descending order, were *Holocentrus* species (squirrelfish), *Haemulon flavolineatum* (French grunt), *Acanthurus bahianus* (ocean surgeonfish), the *Chaetodontidae* family (butterflyfish), and the *Pomacentridae* family (damselfish) (Fig. 3A), noting that ocean surgeonfish and butterflyfish had the same frequency. The six most abundant fish densities, in descending order, are squirrelfish, French grunt, butterflyfish, *Halichoeres bivittatus* (slippery dick), ocean surgeonfish, and damselfish, noting that ocean surgeonfish and damselfish had the same frequency (Fig. 3B). In these statistics, "squirrelfish" includes longspine squirrelfish and reef squirrelfish due to scarcity of the latter two species in the caves chosen. French grunt and squirrelfish tend to be the most dominant and co-occurring species among marine caves in Bermuda bays shown by both their high frequency and abundance.

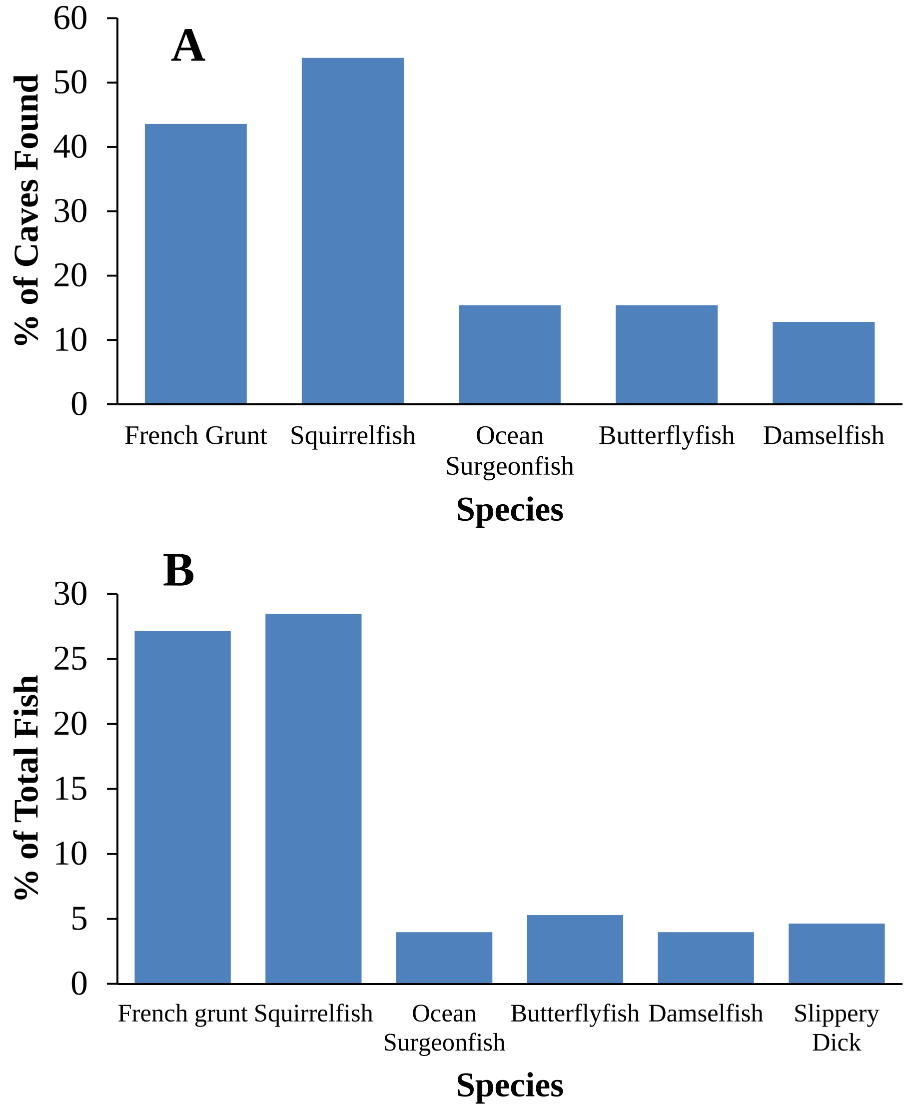

Figure 3; Most abundant fish species (in terms of % of caves found in) across the 39 caves sampled (A); Most abundant fish (in terms of % of total fish) across the 39 caves sampled (B). French grunt and squirrelfish are notably more frequent in both instances than any other species seen.

Although care was taken not to scare or disturb the fish while sampling the caves, future studies could use remote video cameras to monitor caves for a period of time. This would reduce human disturbance by giving time for fish to resettle after the camera was deployed. This method could also determine the residence time of species in the caves to see which species occupy the caves most frequently. Performing this experiment at night could show short-term fluctuations in diversity and abundance within the marine caves. It would be beneficial to see the variance of these results when performed during different seasons due to long-term seasonal density fluctuations Size class and time of year can affect population dynamics of reef fish, as shown by Shulman and Ogden (1987). They investigated the relationship between juvenile and adult French grunt (*Haemulon flavolineatum*) population densities. They found that adult French Grunt populations primarily live in reef habitats, whereas juvenile populations live in lagoon habitats. French grunt reef populations are also highest from September to November and lowest from February to June. Shulman (1985) found that daytime interactions among species regarding choice of shelter sites were more combative than dusk and night interactions. Long term deployment of video cameras has the potential to capture diurnal and seasonal interactions among reef fishes. Data on the aforementioned variables for the Bermuda study sites would be a valuable addition to the current data.

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