Sharks can have powerful influence on the structure of marine ecosystems (Hammerschlag, Schmitz et al. 2019). Many populations of large sharks are undergoing global decline (Dulvy, Fowler et al. 2014). To effectively manage the populations of large sharks, greater understanding on the determinants of the abundance and distribution of sharks is needed.

INVESTIGATING THE DISTRIBUTIONAL ABUNDANCE AND DIVERSITY PATTERNS OF TELEOST FISHES IN BISCAYNE BAY (FLORIDA) AND ITS POTENITAL INFLUENCE ON SHARK HABITAT USE

Julia Saltzman, Dr. Neil Hammerschlag

University of Miami Shark Research and Conservation, Rosenstiel School of Marine and Atmospheric Science

ABSTRACT

For top terrestrial predators, the main driver of their abundance and behavior is prey availability. While some studies have found the relative abundance of prey influence the relative abundance of sharks, more studies are needed to confirm this phenomena. This study used baited remote underwater video stations (BRUVS) and scientific drumlines to examine the relationships between the abundance of sharks and the availability of their prey. Six trophic specific relationships were found. These relationships support that the distribution of animals is not randomly through space; their abundance is influenced by a variety of factors, including the availability of prey and the risk of predation.

OBJECTIVES

Developing an understanding of the foraging behavior and spatial distribution of apex predators is necessary for a complete understanding of marine ecosystems. This study addressed following three questions:

1. Is the abundance of sharks related to the abundance of teleosts?

2. Given the wide diversity of trophic levels among sharks and teleosts, is there a relationship between the abundance of sharks at different trophic levels and the abundance of teleosts at different trophic levels?

3. Is there a relationship between the abundance of large bodied/medium bodied sharks sand the abundance of small bodied sharks?

Results of this thesis will contribute to the growing knowledge base on shark behavioral ecology, and potential for conservation and management strategies. This study seeks to examine the ramifications of prey abundance on shark habitat use on multiple time scales across a variety of shark species with different trophic positions. Additionally, the proximity of the study location to the Miami metropolitan areas allows for exploration on the effects of urbanization on both fish abundance and diversity and shark abundance and diversity.

METHODS

Study Site

Biscayne Bay is a shallow subtropical lagoon on the southeastern coast of Florida and is bordered to the west by the mainland and to the east by barrier islands and keys. This naturally clear-water bay is enriched with tropical flora and fauna. The ecosystems of Biscayne Bay have been subject to severe anthropogenic impacts as the Miami metropolitan area expands. Miami-Dade is the second largest county area in the state of Florida, and it is home to the state's largest population. There are nearly 2.5 million people living in the Miami area, with many more visiting the area as a tourist destination each year. Prior to the population boom of the 20th century, Miami-Dade was home to mangroves, freshwater marshes, seagrass beds, and coral reefs. Over the past one hundred years of development, many of these ecosystems have been altered and removed to make way for massive amounts of waterfront development. Many of these ecosystems are fragments of what they once were, surrounded by other, particularly urban land uses (Alonso and Heinen 2011).

Scientific Drumlines for Medium and Large Sharks

The relative abundance of large bodied, medium bodied, and nurse sharks measured using a drumline system. Sampling was done opportunistically; drumline surveys are contributing to several other long-term research projects. The large hook size, and fileted bait targets primarily larger species. Sampling occurred within the Biscayne Bay and Miami area between September 2019- March 2020, including both dry (November-April) and wet seasons (May-October). Sharks were captured and CPUE was measured using a standardized drumline system, as described in Gallagher et. al 2014. Drumlines were deployed in a transect line at each sampling location and left to soak for one hour. After an hour had passed, the drumlines were retrieved and redeployed. Sharks caught on lines were quickly reeled in and secured on a semi-submerged platform. The sharks were released in a sampling process which took no more than seven minutes.

Baited Remote Underwater Video Stations (BRUVS) for small sharks and teleost fishes

To measure the relative abundance of small bodied sharks and teleost fishes BRUVS were used. BRUVS were deployed at the beginning and end of each set of drumlines, at the same sampling locations. Due to the bait type (sardines) the species which are primarily surveyed are teleost fish and small bodied sharks. BRUVS are a valuable tool as they enable scientists to survey fishes in a variety of areas without requiring the capturing and handling of fish. The BRUVS used in this study consisted of a rig made of PVC piping and a camera mounted in a fixed position (Figure 2.3). The fixed positioning allows the recording of organisms which come into view. Fish and small bodied shark counts were recorded using the MaxN method (Cappo, Speare et al. 2004). MaxN is advantageous for several reasons. This method counts the maximum number of individual fish of a given species in a field of view at one time (Cappo, Speare et al. 2004), the MaxN for each one-hour deployment was recorded for small sharks, teleosts, and each defined trophic guild of teleost fishes. This prevents individual fish from being counted more than once.

Trophic Levels

Prior to any analysis, the species which were surveyed were provisioned into trophic levels based upon their past studies on diets and sizes

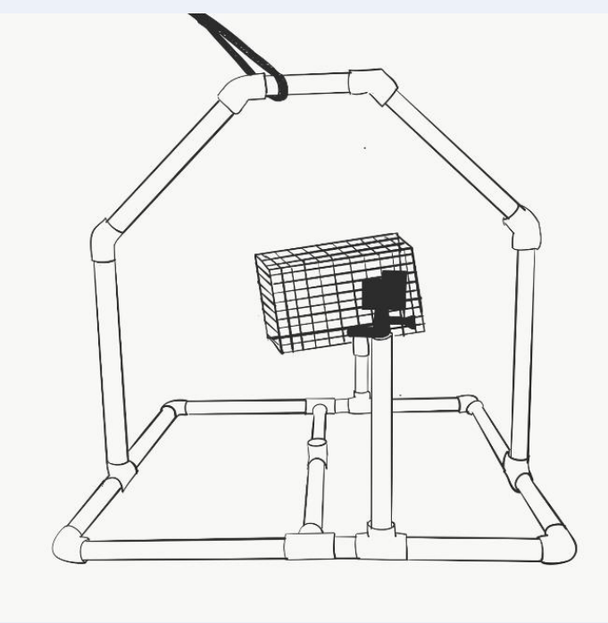
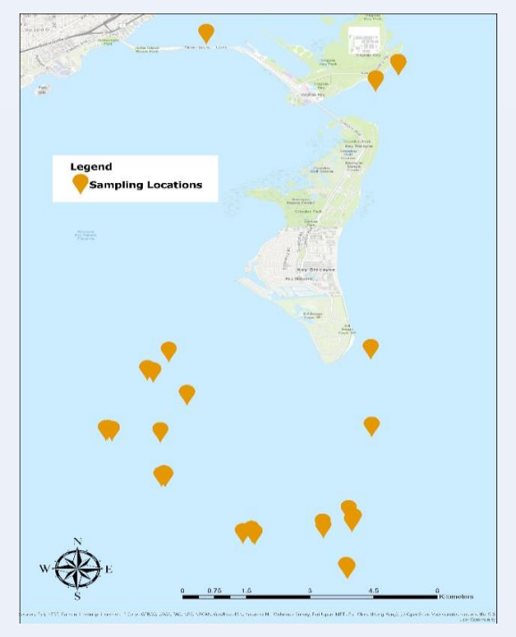


Diagram of BRUV used in this study. The BRUVS used in this study consisted of a rig made of PVC piping and a camera mounted in a fixed position.



Study locations throughout Biscayne Bay.

RESULTS

Between September 2019 and March 2020, a total of 98 sharks at 15 different sampling sites were caught using drumline surveys, all were tagged and released a standard scientific workup was conducted for the purpose of other research projects. The 98 sharks were from 8 different species. Within the same timeframe 40 baited remote underwater videos were deployed at the 15 different sampling sites. A variety of fish were identified.

Across 27 correlations, six significant relationships were found between potential predators and prey:

Medium Bodied Sharks vs. Teleosts: There is a moderate positive relationship (Spearman Rho= 0.341, P-Value=0.034) between the abundance of medium bodied sharks and the abundance of teleosts (Figure 2.4),

Large Bodied Sharks vs. Piscivores: There is a moderate positive relationship (Spearman Rho= 0.348, P-Value=0.030) between the abundance of large bodied sharks and the abundance of piscivores (Figure 2.5).

Nurse Sharks vs. Generalist Omnivores: There is a moderate negative relationship (Spearman Rho=0.323, P-Value=0.045) between the abundance of nurse sharks and the abundance of generalist omnivores (Figure 2.6).

Small Bodied Sharks vs. Crustacean Zoobenthivores: There is a moderate positive relationship (Spearman Rho= 0.335, P-Value=0.037) between the abundance of small bodied sharks and the abundance of crustacean zoobenthivores (Figure 2.7)

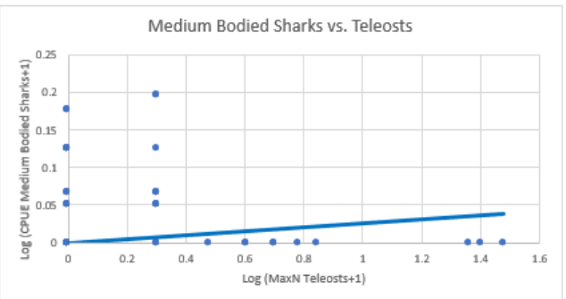
.

Medium Bodied Sharks vs. Crustacean Zoobenthivores: There is a moderate positive relationship (Spearman Rho= 0.338, P-Value=0.035) between the abundance of medium bodied sharks and the abundance of crustacean zoobenthivores (Figure 2.8)

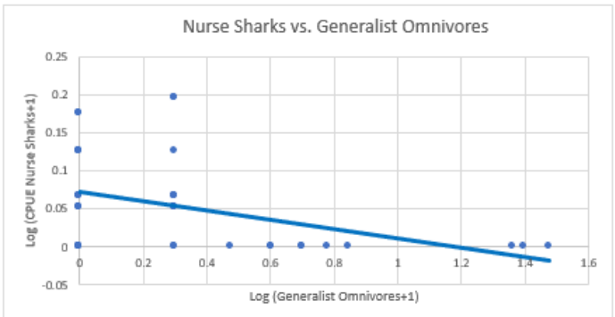
Large Bodied Sharks vs. Small Bodied Sharks: There is a strong negative relationship (Spearman Rho=-0.414, P-Value=0.009) between the abundance of large bodied sharks and the abundance of small bodied sharks (Figure 2.9).

	Teleosts		Piscivores		Herbivores		Generalist Omnivores		Crustcean Zoobenthivores		Small Bodied Sharks	
	r	p	r	p	r	p	r	p	r	p	r	p
Small Bodied Sharks	0.314	0.053	-0.053	0.748	0.03	0.855	0.106	0.522	0.335	0.037		
Medium Bodied Sharks	0.341	0.034	0.107	0.518	0.277	0.088	0.21	0.183	0.338	0.035	-0.198	0.226
Nurse Sharks	-0.186	0.257	0.13	0.429	-0.277	0.165	0.323	0.045	-0.202	0.217	-0.094	0.568
Large Bodied Sharks	0.007	0.996	0.348	0.03	-0.131	0.522	0.005	0.976	0.042	0.801	-0.414	0.009
highlights denotes a significant relationship												

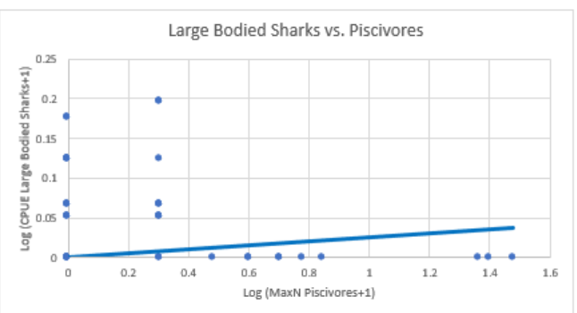
Results of Spearman rho test for correlation for deployment MaxN and daily CPUE.



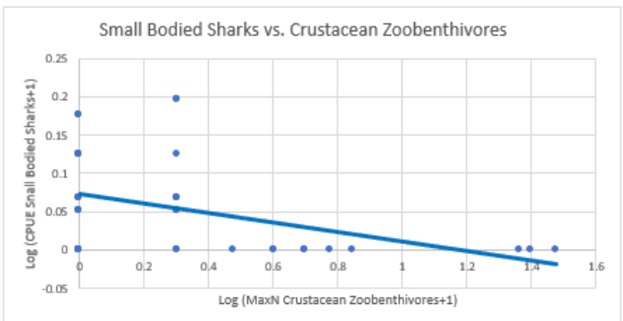
significant relationship between relative abundance of teleosts and relative abundance of medium bodied sharks fit with a linear regression.



significant relationship between relative abundance of generalist omnivores and relative abundance of nurse sharks fit with a linear regression.



significant relationship between relative abundance of piscivores and relative abundance of large bodied sharks fit with a linear regression.



significant relationship between relative abundance of crustacean zoobenthivores and relative abundance of small bodied sharks fit with a linear regression.

CONCLUSIONS

The distribution of animals is not randomly through space, their movement ecology is influenced by a variety of factors; one of these factors is the landscape of fear. The landscape of fear model is a concept in ecology which predicts how animals move throughout their environment- it predicts that as an animal's landscape changes from low to high risk of predation, prey will alter their behavior to mitigate predation risk (Hammerschlag, Broderick et al. 2015). The negative correlation between the relative abundance of large bodied sharks and small bodied sharks displays the potential for the ability of surveyed small bodied sharks in Biscayne Bay to recognize and even mediate the risk of predation, affirming the concept of the landscape of fear. This also displays the top down affects of large sharks in the Biscayne Bay ecosystem. The results of this study support the idea that predators not only exert consumptive effects on their prey (causing mortality), but they also have non-consumptive (risk effects) on their, altering the foraging behavior, relative abundance, and habitat use of their prey.

While this study found correlation between prey relative abundance and shark relative abundance, it cannot confirm that prey abundance has a direct effect on shark habitat use as whole. Future studies can seek to use this data or methodology combined with the active tracking of sharks, whether it be through satellite telemetry or acoustic telemetry to examine how prey abundance in different areas throughout the Biscayne Bay affects shark residency patterns, movements, and habitat use. Moreover, with more active tracking and further BRUV surveys- and understanding of the foraging behavior and site fidelity in relationship to prey abundance can be developed. In order to truly understand the trophic relationships between sharks and fishes- more data is needed. For example, stable isotope analysis can be used for assessing the trophic positions and diet of elasmobranchs to estimate their trophic level and role in their ecosystems (Shiffman, Gallagher et al. 2012). Data such as stable isotope analysis, active tracking, abundance data from CPUE and BRUVS can be used comprehensively to better understand ecosystems and interactions between predators and prey. Rather than a simple focus on characteristics and ecology of the predator, there is a predation (Hammerschlag 2019).

REFERENCES

Alonso, J. and J. T. Heinen (2011). "Miami Dade County's Environmentally Endangered Lands Program: Local Efforts for a Global Cause." **31 %J Natural Areas Journal**(2): 183-189, 187.

Barnett, A., K. G. Abrantes, J. D. Stevens, B. D. Bruce and J. M. Semmens (2010). "Fine-scale movements of the Broadnose Sevengill shark and its main prey, the Gummy shark." PloS one **5**(12): e15464-e15464.

Bethea, D., J. Carlson, J. Buckel and M. Passerotti (2006). "Ontogenetic and site-related trends in the diet of the Atlantic sharpnose shark Rhizoprionodon terranovae from the Northeast Gulf of Mexico." BULLETIN OF MARINE SCIENCE **78**: 287-307.

Bethea, D. M., L. Hale, J. K. Carlson, E. Cortés, C. A. Manire and J. Gelsleichter (2007). "Geographic and ontogenetic variation in the diet and daily ration of the bonnethead shark, Sphyrna tiburo, from the eastern Gulf of Mexico." Marine Biology **152**(5): 1009-1020.

Boyer, J. N., C. R. Kelble, P. B. Ortner and D. T. Rudnick (2009). "Phytoplankton bloom status: Chlorophyll a biomass as an indicator of water quality condition in the southern estuaries of Florida, USA." Ecological Indicators **9**(6, Supplement): S56-S67.

Brock, R. E. (1979). "An experimental study on the effects of grazing by parrotfishes and role of refuges in benthic community structure." Marine Biology **51**(4): 381-388.

Brown, G. E., A. C. Rive, M. C. O. Ferrari and D. P. Chivers (2006). "The dynamic nature of antipredator behavior: prey fish integrate threat-sensitive antipredator responses within background levels of predation risk." Behavioral Ecology and Sociobiology **61**(1): 9-16.

Caccia, V. G. and J. N. Boyer (2005). "Spatial patterning of water quality in Biscayne Bay, Florida as a function of land use and water management." Marine Pollution Bulletin **50**(11): 1416-1429.

Cappo, M., P. Speare and G. De'ath (2004). "Comparison of baited remote underwater video stations (BRUVS) and prawn (shrimp) trawls for assessments of fish biodiversity in inter-reefal areas of the Great Barrier Reef Marine Park." Journal of Experimental Marine Biology and Ecology **302**(2): 123-152.

Castro, J. I. (1996). "Biology of the Blacktip Shark, Carcharhinus Limbatus, off the Southeastern United States." Bulletin of Marine Science **59**(3): 508-522.

Castro, J. I. (2000). "The Biology of the Nurse Shark, Ginglymostoma cirratum, Off the Florida East Coast and the Bahama Islands." Environmental Biology of Fishes **58**(1): 1-22.

Clark, E. and D. R. Nelson (1997). "Young whale sharks, Rhincodon typus, feeding on a copepod bloom near La Paz, Mexico." Environmental Biology of Fishes **50**(1): 63-73.

Cliff, G. (1995). "Sharks caught in the protective gill nets off KwaZulu-Natal, South Africa. 8. The Great hammerhead shark Sphyrna mokarran (Rüppell)." South African Journal of Marine Science **15**(1): 105-114.

Collins, A. B., M. R. Heupel and C. A. Simpfendorfer (2008). "Spatial Distribution and Long-term Movement Patterns of Cownose Rays Rhinoptera bonasus Within an Estuarine River." Estuaries and Coasts **31**(6): 1174-1183.

Dancey, C. and J. Reidy (2004). Statistics Without Maths for Psychology.

Dudley, S. F. J. and G. Cliff (1993). "Sharks caught in the protective gill nets off Natal, South Africa. 7. The blacktip shark Carcharhinus limbatus (Valenciennes)." South African Journal of Marine Science **13**(1): 237-254.

Dulvy, N. K., S. L. Fowler, J. A. Musick, R. D. Cavanagh, P. M. Kyne, L. R. Harrison, J. K. Carlson, L. N. K. Davidson, S. V. Fordham, M. P. Francis, C. M. Pollock, C. A. Simpfendorfer, G. H. Burgess, K. E. Carpenter, L. J. V. Compagno, D. A. Ebert, C. Gibson, M. R. Heupel, S. R. Livingstone, J. C. Sanciangco, J. D. Stevens, S. Valenti and W. T. White (2014). "Extinction risk and conservation of the world's sharks and rays." eLife **3**: e00590.

Hammerschlag, N. (2019). "Quantifying shark predation effects on prey: dietary data limitations and study approaches." Endangered Species Research **38**: 147-151.

Hammerschlag, N., A. C. Broderick, J. W. Coker, M. S. Coyne, M. Dodd, M. G. Frick, M. H. Godfrey, B. J. Godley, D. B. Griffin, K. Hartog, S. R. Murphy, T. M. Murphy, E. R. Nelson, K. L. Williams, M. J. Witt and L. A. Hawkes (2015). "Evaluating the landscape of fear between apex predatory sharks and mobile sea turtles across a large dynamic seascape." Ecology **96**(8): 2117-2126.

Hammerschlag, N., O. J. Schmitz, A. S. Flecker, K. D. Lafferty, A. Sih, T. B. Atwood, A. J. Gallagher, D. J. Irschick, R. Skubel and S. J. Cooke (2019). "Ecosystem Function and Services of Aquatic Predators in the Anthropocene." Trends in Ecology & Evolution **34**(4): 369-383.

Hayward, M. W., J. O'Brien and G. I. H. Kerley (2007). "Carrying capacity of large African predators: Predictions and tests." Biological Conservation **139**(1): 219-229.

Heithaus, M., L. Dill, G. Marshall and B. Buhleier (2002). "Habitat use and foraging behavior of tiger sharks (Galeocerdo cuvier) in a seagrass ecosystem." Marine Biology **140**(2): 237-248.

Heithaus, M. R. (2001). "The Biology of Tiger Sharks, Galeocerdo Cuvier, in Shark Bay, Western Australia: Sex Ratio, Size Distribution, Diet, and Seasonal Changes in Catch Rates." Environmental Biology of Fishes **61**(1): 25-36.

Heithaus, M. R., A. J. Wirsing, D. Burkholder, J. Thomson and L. M. Dill (2009). "Towards a predictive framework for predator risk effects: the interaction of landscape features and prey escape tactics." Journal of Animal Ecology **78**(3): 556-562.

Kempster, R. M., N. S. Hart and S. P. Collin (2013). "Survival of the stillest: predator avoidance in shark embryos." PloS one **8**(1): e52551-e52551.

Luczkovich, J. J., G. P. Ward, J. C. Johnson, R. R. Christian, D. Baird, H. Neckles and W. M. Rizzo (2002). "Determining the trophic guilds of fishes and macroinvertebrates in a seagrass food web." Estuaries **25**(6): 1143-1163.

Matich, P. and M. R. Heithaus (2012). "Effects of an extreme temperature event on the behavior and age structure of an estuarine top predator, Carcharhinus leucas." Marine Ecology Progress Series **447**: 165-178.

Mourier, J., J. Maynard, V. Parravicini, L. Ballesta, E. Clua, Michael L. Domeier and S. Planes (2016). "Extreme Inverted Trophic Pyramid of Reef Sharks Supported by Spawning Groupers." Current Biology **26**(15): 2011-2016.

Musick, J. A., G. Burgess, G. Cailliet, M. Camhi and S. Fordham (2000). "Management of Sharks and Their Relatives (Elasmobranchii)." Fisheries **25**(3): 9-13.

Newman, S. P., R. D. Handy and S. H. Gruber (2010). "Diet and prey preference of juvenile lemon sharks Negaprion brevirostris." Marine Ecology Progress Series **398**: 221-234.

Poulakis, G. R., P. W. Stevens, A. A. Timmers, T. R. Wiley and C. A. Simpfendorfer (2011). "Abiotic affinities and spatiotemporal distribution of the endangered smalltooth sawfish, <i>Pristis pectinata</i>, in a south-western Florida nursery." Marine and Freshwater Research **62**(10): 1165-1177.

Roessler, M. A. and G. L. Beardsley (1974). "BISCAYNE BAY: ITS ENVIRONMENT AND PROBLEMS." Florida Scientist **37**(4): 186-204.

Santos, R. O., G. Varona, C. L. Avila, D. Lirman and L. Collado-Vides (2020). "Implications of macroalgae blooms to the spatial structure of seagrass seascapes: The case of the Anadyomene spp. (Chlorophyta) bloom in Biscayne Bay, Florida." Marine Pollution Bulletin **150**: 110742.

Schlaff, A. M., M. R. Heupel and C. A. Simpfendorfer (2014). "Influence of environmental factors on shark and ray movement, behaviour and habitat use: a review." Reviews in Fish Biology and Fisheries **24**(4): 1089-1103.

Seamone, S., T. Blaine and T. E. Higham (2014). "Sharks modulate their escape behavior in response to predator size, speed and approach orientation." Zoology **117**(6): 377-382.

Shiffman, D. S., A. J. Gallagher, M. D. Boyle, C. M. Hammerschlag-Peyer and N. Hammerschlag (2012). "Stable isotope analysis as a tool for elasmobranch conservation research: a primer for non-specialists." Marine and Freshwater Research **63**(7): 635-643.

Simpfendorfer, C. A., A. B. Goodreid and R. B. McAuley (2001). "Size, Sex And Geographic Variation in the Diet of the Tiger Shark, Galeocerdo Cuvier, From Western Australian Waters." Environmental Biology of Fishes **61**(1): 37-46.

Sims, D. W., A. M. Fox and D. A. Merrett (1997). "Basking shark occurrence off south-west England in relation to zooplankton abundance." Journal of Fish Biology **51**(2): 436-440.

William, D. H., T. G. Rachel, K. BjÃƒÂ¶rn and E. J. Robert (2001). "Whale sharks Rhincodon typus aggregate to feed on fish spawn in Belize." Marine Ecology Progress Series **215**: 275-282.

Williams, T. M., J. A. Estes, D. F. Doak and A. M. Springer (2004). "KILLER APPETITES: ASSESSING THE ROLE OF PREDATORS IN ECOLOGICAL COMMUNITIES." Ecology **85**(12): 3373-3384.

ACKNOWLEDGEMENTS

Thank you to Dr. Neil Hammerschlag for your constant support and guidance, and to other committee members Dr. Babcock and Maria Estevanez for all your help. This research was funded by SURGE (small undergraduate research grant) and the Mastraini award.