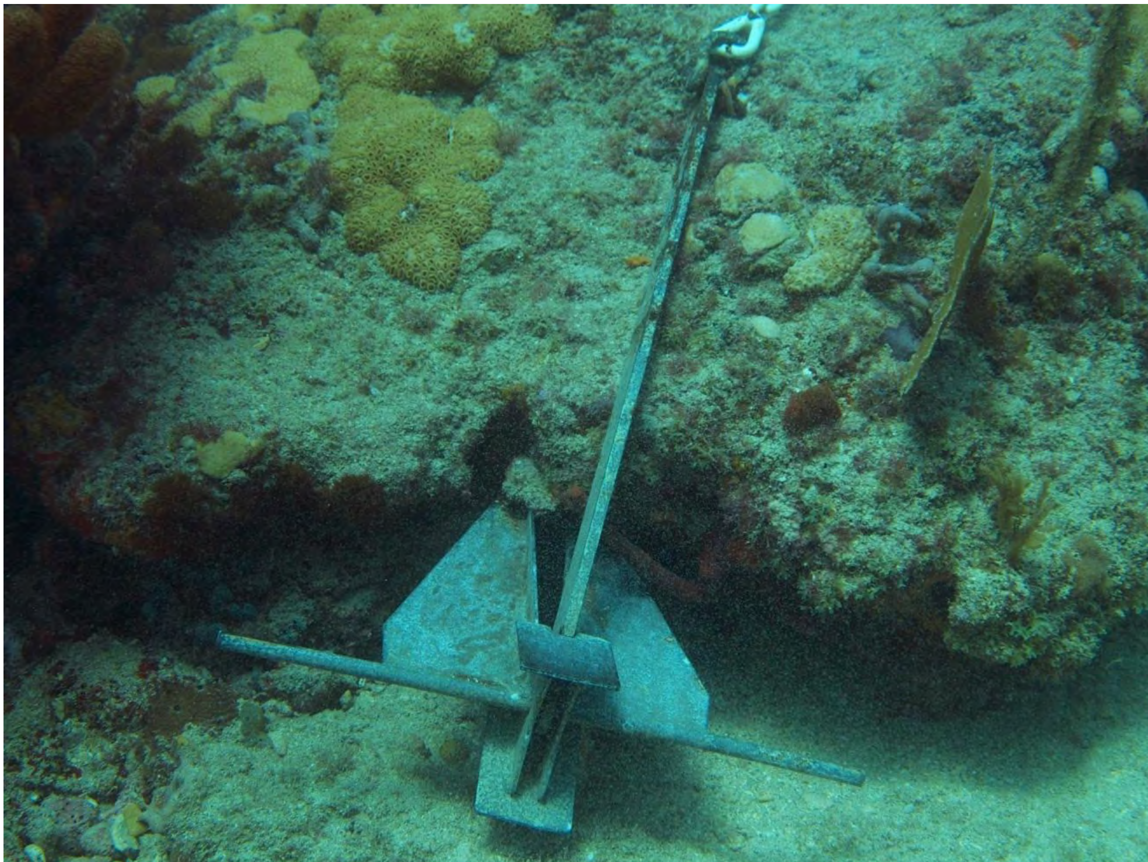
Determining Coral Reef Impacts Associated with Boat Anchoring and User Activity in Southeast Florida



Southeast Florida Coral Reef Initiative
Fishing, Diving, and Other Uses
Local Action Strategy Project 33B

Southeast Florida Coral Reef Initiative
Acting above to protect what's below.

Determining Coral Reef Impacts Associated with Boat Anchoring and User Activity in Southeast Florida

Final Report Prepared By:

Donald C. Behringer PhD

Robert A. Swett PhD

Thomas K. Frazer PhD

University of Florida
School of Forest Resources and Conservation
Fisheries and Aquatic Sciences
7922 NW 71st Street, Gainesville, FL 32653
behringer@ufl.edu

August 23th, 2011

Completed in Fulfillment of Contract RM082 for

Southeast Florida Coral Reef Initiative
Fishing, Diving, and Other Uses
Local Action Strategy Project 33B

and

Florida Department of Environmental Protection
Coral Reef Conservation Program
1277 N.E. 79th Street Causeway
Miami, FL 33138

This report should be cited as follows:
Behringer DC, Swett RA and TK Frazer. 2011. Determining coral reef impacts associated with boat anchoring and user activity in southeast Florida. Florida Department of Environmental Protection - Coral Reef Conservation Program, Miami Beach, FL. Pp 66.

This project and the preparation of this report were funded by a Coastal Zone Management grant from the National Oceanic and Atmospheric Administration through a contract with the Office of Coastal and Aquatic Managed Areas of the Florida Department of Environmental Protection.

Table of Contents

List of Figures iii

List of Tables v

Executive Summary xi

1.0 Introduction 1

2.0 Goals and Objectives 3
- 2.1 Goals 3
- 2.2 Objectives 3

3.0 Methods 3
- 3.1 Geographic range 3
- 3.2 Site selection and survey frequency 3
- 3.3 Site design 9
- 3.4 Site characterization 9
- 3.5 Damage assessments 10
- 3.6 Recovery assessment 11
- 3.7 Statistical analysis 12
  - 3.7.1 Analysis of year 1 – instantaneous damage assessment by use level and county 12
  - 3.7.2 Analysis of yearly damage by use level and county 12
  - 3.7.3 Analysis of recovery 12
  - 3.7.4 Analysis of marine debris 13

4.0 Results 13
- 4.1 Year 1 – Instantaneous damage assessment by use level and county 13
  - 4.1.1 Hard corals and barrel sponges combined 13
  - 4.1.2 Gorgonians only 19
  - 4.1.3 Total damage for hard corals, barrel sponges, and gorgonians combined 23
- 4.2 Yearly damage by use level and county 27
  - 4.2.1 Hard corals and barrel sponges combined 27
  - 4.2.2 Gorgonians only 34
  - 4.2.3 Total damage for hard corals, barrel sponges, and gorgonians combined 41
- 4.3 Recovery 48
  - 4.3.1 Recovery of year 1 versus year 2 damage 48
  - 4.3.2 Recovery of “new” damage versus damage of unknown age 53
- 4.4 Marine debris 56
- 4.5 Bleaching and disease 60
- 4.6 Environmental correlations 60

5.0 Discussion 62

5.1 Instantaneous damage 62
5.2 Yearly damage 63
5.3 Recovery 63
5.4 Marine debris 64
5.5 Environmental correlates 64
5.6 Study limitations 65
5.7 Conclusions 65

6.0 Literature cited 66

List of Figures

Figure 1. Study area boundaries in Miami-Dade, Broward, and Palm Beach counties. 5

Figure 2. Site locations in Miami-Dade, Broward, and Palm Beach counties. 6

Figure 3. Site survey design showing four 25 m transects in the cardinal directions. Transects were set in the cardinal directions to cover a large area of reef while increasing relocation ease for subsequent surveys. 9

Figure 4. Year 1 percentage of hard corals and barrel sponges damaged (percentage of the total number of hard corals and barrel sponges) as a function of use level and southeast Florida county. 18

Figure 5. Year 1 percentage of gorgonians damaged (percentage of the total number of gorgonians), by use level and southeast Florida county. 22

Figure 6. Year 1 percentage of all organisms damaged (percentage of the total number of all organisms), by use level and southeast Florida county. 26

Figure 7. Year 2 percentage of hard corals and barrel sponges damaged (percentage of the total number of hard corals and barrel sponges), by use level and southeast Florida county. 31

Figure 8. Year 3 percentage of hard corals and barrel sponges damaged (percentage of the total number of hard corals and barrel sponges), by use level and southeast Florida county. 32

Figure 9. Yearly percentage of hard corals and barrel sponges damaged (percentage of the total number of hard corals and barrel sponges), by southeast Florida county 33

Figure 10. Year 2 percentage of gorgonians damaged (percentage of the total number of gorgonians), by use level and southeast Florida county. 38

Figure 11. Year 3 percentage of gorgonians damaged (percentage of the total number of gorgonians), by use level and southeast Florida county. 39

Figure 12. Yearly percentage of gorgonians damaged (percentage of the total number of gorgonians), by southeast Florida county 40

Figure 13. Year 2 percentage of all organisms damaged (percentage of the total number of all organisms), by use level and southeast Florida county. 45

Figure 14. Year 3 percentage of all organisms damaged (percentage of the total number of all organisms), by use level and southeast Florida county. 46

Figure 15. Yearly percentage of all organisms damaged (percentage of the total number of all organisms), by southeast Florida county. 47

Figure 16. Mean recovery rank for damaged organisms in year 2 that were first observed in year 1, by county and use level. 51

Figure 17. Mean recovery rank in year 3 of damaged organisms first observed in years 1 and 2, by county and use level. 52

Figure 18. Mean recovery rank for damaged organisms in year 3 that were first observed in year 2, by county and use level. 55

Figure 19. Percentage of marine debris in each county as a percentage of all the marine debris in the county. "Other" debris includes anything that did not fit the other categories including plastic cups, pieces of glass, plastic bags, etc. N = 220 unique pieces of marine debris. 58

Figure 20. Percentage of marine debris in each county as a percentage of all the marine debris observed in the tri-county study area. "Other" debris includes anything that did not fit the other categories including plastic cups, pieces of glass, plastic bags, etc. N = 220 unique pieces of marine debris. 59

List of Tables

Table 1. Coordinates for the center of research sites in southeast Florida. Use levels are abbreviated as follows: high-use diving (HD), high-use fishing (HF), and low-use (L). 7

Table 2. Dates research sites in southeast Florida were surveyed. 8

Table 3. Benthic coverage types and abbreviations used in site characterization. 10

Table 4. Ranking scale used to determine the recovery status of damaged organisms. 11

Table 5. Percentage of each organism type damaged by county and use level (percentage of the total number of each). Use levels are abbreviated as follows: high-use diving (HD), high-use fishing (HF), and low-use (L). Percentages are back-transformed least squares means. 14

Table 6. Percentage of organisms damaged by use level as a percentage of the total number per use level. Use levels are abbreviated as follows: high-use diving (HD), high-use fishing (HF), and low-use (L). Percentages are back-transformed least squares means. 14

Table 7. Year 1 least squares means by use level for number of hard corals and barrel sponges damaged per site as a percentage of the total number of hard corals and barrel sponges on each site. Year 1 damage includes all cumulative damage until the time of the first survey. 15

Table 8. Year 1 differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) of hard coral and barrel sponge damage between use levels. Year 1 damage includes all cumulative damage until the time of the first survey. 15

Table 9. Percentage of organisms damaged by county as a percentage of the total number per county. Percentages are back-transformed least squares means. 15

Table 10. Year 1 least squares means by county for number of hard corals and barrel sponges damaged per site as a percentage of the total number of hard corals and barrel sponges on each site. Year 1 damage includes all cumulative damage until the time of the first survey. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale. 16

Table 11. Year 1 differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) of hard coral and barrel sponge damage between counties. Year 1 damage includes all cumulative damage until the time of the first survey. 16

Table 12. Year 1 least squares means by use level*county interaction for number of hard corals and barrel sponges damaged per site as a percentage of the total number of hard corals and barrel sponges on each site. Year 1 damage includes all cumulative damage until the time of the first survey. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale. 17

Table 13. Year 1 least squares means by use level for number of gorgonians damaged per site as a percentage of the total number of gorgonians on each site. Year 1 damage includes all cumulative damage until the time of the first survey. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale. 19

Table 14. Year 1 differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) of gorgonian damage between use levels. Year 1 damage includes all cumulative damage until the time of the first survey. 19

Table 15. Year 1 least squares means by county for number of gorgonians damaged per site as a percentage of the total number of gorgonians on each site. Year 1 damage includes all cumulative damage until the time of the first survey. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale. 20

Table 16. Year 1 differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) of gorgonian damage between counties. Year 1 damage includes all cumulative damage until the time of the first survey. 20

Table 17. Year 1 least squares means by use level*county interaction for number of gorgonians damaged per site as a percentage of the total number of gorgonians on each site. Year 1 damage includes all cumulative damage until the time of the first survey. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale. 21

Table 18. Year 1 least squares means by use level for number of all damaged organisms combined per site as a percentage of the total number of all damaged organisms combined on each site. Year 1 damage includes all cumulative damage until the time of the first survey. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale. 23

Table 19. Year 1 differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) of all damaged organisms combined, between use levels. Year 1 damage includes all cumulative damage until the time of the first survey. 23

Table 20. Year 1 least squares means by county for number of all damaged organisms combined per site as a percentage of the total number of all damaged

organisms combined on each site. Year 1 damage includes all cumulative damage until the time of the first survey. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale. 24

Table 21. Year 1 differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) for all damaged organisms combined, between counties. Year 1 damage includes all cumulative damage until the time of the first survey. 24

Table 22. Year 1 least squares means by use level*county interaction for number of all organisms damaged per site as a percentage of the total number of all damaged organisms combined on each site. Year 1 damage includes all cumulative damage until the time of the first survey. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale. 25

Table 23. Percentage of each organism type damaged by county and use level (percentage of the total number of each) in years 2 and 3. Use levels are abbreviated as follows: high-use diving (HD), high-use fishing (HF), and low-use (L). Percentages are back-transformed least squares means. 27

Table 24. Percentage of organisms damaged by county as a percentage of the total number per county in years 2 and 3. Percentages are back-transformed least squares means. 28

Table 25. Percentage of organisms damaged by use level as a percentage of the total number per use level in years 2 and 3. Use levels are abbreviated as follows: high-use diving (HD), high-use fishing (HF), and low-use (L). Percentages are back-transformed least squares means. 28

Table 26. Results of a repeated-measures linear mixed model analysis of the effects of year, use level, and county on the percentage of hard corals and barrel sponges damaged per site as a percentage of the total number of hard corals and barrel sponges on each site. 29

Table 27. Least squares means by year for the percentage of hard corals and barrel sponges damaged per site as a percentage of the total number of hard corals and barrel sponges on each site. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale. 29

Table 28. Differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) for the percentage of hard corals and barrel sponges damaged, between years. 29

Table 29. Least squares means by county for the percentage of hard corals and barrel sponges damaged per site as a percentage of the total number of hard

corals and barrel sponges on each site. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale. 30

Table 30. Differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) for the percentage of hard corals and barrel sponges damaged, between counties. 30

Table 31. Results of a repeated-measures linear mixed model analysis of the effects of year, use level, and county on the percentage of gorgonians damaged per site as a percentage of the total number of gorgonians on each site. 34

Table 32. Least squares means by year for the percentage of gorgonians damaged per site as a percentage of the total number of gorgonians on each site. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale. 35

Table 33. Differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) for the percentage of gorgonians damaged, between years. 35

Table 34. Least squares means by county for the percentage of gorgonians damaged per site as a percentage of the total number of gorgonians on each site. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale. 35

Table 35. Differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) for the percentage of gorgonians damaged, between counties. 36

Table 36. Least squares means by county*year interaction for the percentage of gorgonians damaged per site as a percentage of the total number of gorgonians on each site. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale. 36

Table 37. Tests of the county*year interaction effect by year for the percentage of gorgonians damaged per site as a percentage of the total number of gorgonians on each site. 36

Table 38. Least squares means simple effect comparison of the county*year interaction by year for the percentage of gorgonians damaged per site as a percentage of the total number of gorgonians on each site. 37

Table 39. Least squares means by use level for the percentage of gorgonians damaged per site as a percentage of the total number of gorgonians on each site. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale. 37

Table 40. Differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) for the percentage of gorgonians damaged, between use levels. 37

Table 41. Results of a repeated-measures linear mixed model analysis of the effects of year, use level, and county on the percentage of all organisms damaged per site as a percentage of the total number of organisms on each site. 41

Table 42. Least squares means by use level for the percentage of all organisms damaged per site as a percentage of all organisms on each site. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale. 41

Table 43. Differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) for the percentage of all organisms damaged, between years. 42

Table 44. Least squares means by county for the percentage of all organisms damaged per site as a percentage of all organisms on each site. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale. 42

Table 45. Differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) for the percentage of all organisms damaged, between counties. 42

Table 46. Least squares means by county*year interaction for the percentage of all organisms damaged per site as a percentage of all organisms on each site. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale. 43

Table 47. Tests of the county*year interaction effect by year for the percentage of all organisms damaged per site as a percentage of the total number of gorgonians on each site. 43

Table 48. Least squares means simple effect comparison of the county*year interaction by year for the percentage of all organisms damaged per site as a percentage of all organisms on each site. 44

Table 49. Repeated-measures linear model of the effect of use level and county on the recovery rank of all damaged organisms (first observed in year 1 and 2) and assessed in year 3. Year denotes year damage was first observed. 48

Table 50. Least squares means of the recovery rank of all damaged organisms (first observed in year 1 and 2) and assessed in year 3 by year first observed (year), use level, and county. 49

Table 51. Differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) for the recovery rank of damaged organisms first

observed in year 1 and assessed in year 3, and damaged organisms observed in year 2 and assessed in year 3. 50

Table 52. Repeated-measures linear model of the effect of year first observed (year), use level, and county on the recovery rank of damaged organisms observed in year 1 and assessed in year 2, and damaged organisms observed in year 2 and assessed in year 3. Year denotes year damage was first observed...... 53

Table 53. Least squares means of recovery rank of damaged organisms observed in year 1 and assessed in year 2 and damaged organisms observed in year 2 and assessed in year 3, by year first observed (year), use level, and county. 54

Table 54. Results of a repeated-measures linear mixed model on the effects of survey year, use level, and county on the abundance of marine debris. 56

Table 55. Least squares means of debris abundance by survey year and county. 56

Table 56. Differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) among years and counties. 57

Table 57. Correlations between depth, rugosity, and benthic coverage environmental variables and the three damage categories. Calcareous and felshy algae were combined into algae, and rubble and sand were combined into loose substrate to simplify the analysis. 61

Executive Summary

Anchoring can be a major source of damage to coral reefs adjacent to heavily populated areas, resulting in dislodged or broken hard corals, octocorals, and sponges. Southeast Florida has a large human population, and not surprisingly, the coral reefs adjacent to this area receive considerable anchoring pressure.

The Florida Fish and Wildlife Conservation Commission recognizes the importance of coral reefs by listing them as a "priority habitat" and designating their overall habitat threat category as "very high". Several sources of coral reef habitat stress are associated with boating or boating-related activities, including incompatible fishing pressure, fishing gear impacts, boating impacts, and incompatible recreational activities.

This study sought to determine if coral reef use level (high diving, high fishing, and low use) and county (Miami-Dade, Broward, and Palm Beach counties) predicted the amount of damage a reef receives and if the rate of new damage exceeded or was exceeded by the recovery rate. The former would predict that the use level was unsutainable, while the latter would predict the opposite.

This study found that Miami-Dade had significantly more historical (i.e., cumulative) hard coral and barrel sponge damage, more gorgonian damage, and more total damage than either Broward or Palm Beach counties. However, Broward County appeared to experience greater gorgonian damage in year 2 of the study. Although no consistent differences were measured between use types or use intensity levels, it may be that low use sites are sites so degraded by past use or other perterbations that they are no longer attractive to divers and fishermen. Similarly, the lack of consistent differences could have arisen from multi-purpose use of most sites. Regardless of use type, damaged organisms tended to decline rather than recover, and declined more rapidly soon after damage. Similarly, differences in recovery between counties was most likely a function of the date damage occurred. Miami-Dade had greater historical damage than Palm Beach County and thus much of this damage has probably stabilized to a greater extent.

Although not always a direct cause of damage, marine debris can entangle and smother organisms. There were significant differences in the amount of debris observed between counties, but the impact on organisms was not quantified. Palm Beach County had significantly more debris than either Miami-Dade or Broward counties, and this was driven by an exceptionally high amount of fishing line.

Although the use level factor did not identify consistent differences between treatments, this is in itself important. It supports the possibility that all reefs in Miami-Dade, Broward, and Palm Beach counties receive intense pressure and

probably more than they can sustain. The significant difference in damage between Miami-Dade and Broward counties highlights the potential effectiveness of an extensive mooring buoy program and that with an appropriate management system, education, and awareness, damage can be greatly reduced.

1.0 Introduction

Anchoring can be a major source of damage to coral reefs adjacent to heavily populated areas, resulting in dislodged or broken hard corals, octocorals, and sponges (Saphier and Hoffman 2005). Southeast Florida has a large human population (Fig. 1), and not surprisingly, the coral reefs adjacent to this area receive considerable anchoring pressure (Behringer and Swett 2011). Many potential sources of reef degradation such as ocean warming, eutrophication, ocean acidification, and over-fishing are controversial and even if addressed will take years, decades, or longer to reverse. However, unlike global stressors, anchor damage to coral reefs is immediate but manageable. With an appropriate management program, education, and awareness, anchor damage can be greatly reduced or eliminated.

The coral reefs in Florida represent the only barrier reef system in the continental U.S. This exceptional natural resource, when combined with warm tropical water and favorable weather, is a consummate draw for avid boaters, fishermen, and divers from around the world. In fact, based on an analysis of Coast Guard boating statistics over the past decade, Florida has the highest number of registered boats and the sixth highest statewide rate of growth in boater registrations in the United States (U.S. Coast Guard 2009). This magnitude of boating and related activities has led to intense pressure on already strained reef resources.

The Florida Fish and Wildlife Conservation Commission (FWC) recognizes the importance of coral reefs by listing them as a "priority habitat" and designating their overall habitat threat category as "very high" (the highest threat level) in their Florida Wildlife Legacy Initiative Comprehensive Wildlife Conservation Strategy (FWLI). The state of Florida created the FWLI as a conservation plan to meet the intent of the State Wildlife Grants Program, a program created by the U.S. Congress to promote wildlife conservation prior to species reaching the brink of extinction. Of the nearly 1,000 organisms listed in the FWLI as "Species of Greatest Conservation Need" (SGCN), 304 are reef-associated animals, 88 of which are reef invertebrates, and 54 of the invertebrates are corals. Several sources of coral reef habitat stress identified in the FWLI are associated with boating or boating-related activities, including incompatible fishing pressure (rank = very high), fishing gear impacts (rank = high), boating impacts (rank = high), and incompatible recreational activities (rank = medium). One of the four "highest ranking actions identified for abating the source of this stress" in the FWLI is "development of a vessel anchoring management plan and use of mooring buoys" (FWC 2005). Fulfillment of this action requires knowledge of vessel use patterns, associated activities, and their corresponding impacts on coral reefs caused by anchoring and human activities (e.g., fishing and diving).

The former was addressed by FDOU Project 33A (Behringer and Swett 2011). The latter is essential to validate the observations and conclusions drawn from knowledge of the former two, i.e., vessel use patterns and associated activities.

The marine resource professionals, scientists and other stakeholders who developed the Southeast Florida Coral Reef Initiative (SEFCRI) Fishing, Diving, and Other Uses (FDOU) Focus Area prioritized a project to evaluate the impacts associated with boat anchoring and user activities in southeast Florida (Miami-Dade, Broward, Palm Beach counties). A previous SEFCRI FDOU project (FDOU 33A) used aerial surveys to determine use intensity, anchoring pressure, and predominant activities over the entire region. The information on use and activity patterns gained from the aerial surveys was used for this project as the means for identifying reef research sites. The results of this project will give a clearer understanding of the extent and distribution of impacts southeast Florida coral reefs experience and the rate of recovery from these impacts. Data derived from this project will allow resource managers such as the National Oceanic and Atmospheric Administration (NOAA), Florida Department of Environmental Protection (FDEP), the FWC, and county governments to more effectively target conservation efforts on areas receiving the most intensive use and incurring the greatest damage.

2.0 Goals and Objectives

2.1 Goals

The goal of this project was to determine if patterns of reef use intensity or activity type, as identified from aerial surveys performed during FDOU Project 33A, correspond to damage measured on the reef. We also sought to determine if the level of use, and subsequent damage, on those coral reefs is sustainable by assessing the recovery rate of damaged organisms and the rate of new damage.

2.2 Objectives

a) Determine if coral reef use intensity by boat operators correlates with impact levels measured on the reef.
b) Determine if impact level and type can be predicted from user activity type.
c) Determine if the frequency of coral reef injuries or extent of damage exceeds recovery rates.

3.0 Methods

3.1 Geographic range

The south-north geographic range of the study area was delineated by FDOU Project 33A as extending from the Fowey Rocks Lighthouse in the south to the Palm Beach – Martin County line in the north (Fig. 1). Unlike FDOU Project 33A, Martin County was not included in this study due to a lack of benthic habitat maps for this county at the time of the study. The east-west geographic range of the study area was also delineated by FDOU Project 33A as extending from the 35 m isobath in the east to the coastline in the west. Sites were all located on coral reef ground-truthed by the investigators.

3.2 Site selection and survey frequency

Aerial survey data of vessel use patterns from FDOU Project 33A were used to select reefs of varying use and activity type (Fig. 2, Table 1). Use levels included high-use fishing, high-use diving, and low-use control sites in an orthogonal design with four replicates of each use level treatment in each county. The high-use fishing and diving sites in each county represent the highest four densities of boats observed near coral reefs during six aerial surveys of vessel activity in Miami-Dade, Broward, and Palm Beach counties in 2008 (Behringer and Swett 2011). Those six surveys were comprised of two weekdays, two weekends, and two holidays. We limited the number of sites within each county to 12 due to the time required to complete each survey and maintain diver safety. Each coral reef site was surveyed once per year for three years, year 1: 2008-2009, year 2: 2009-2010, year 3: 2010-2011, with approximately 10 – 12 months between surveys (Table 2).

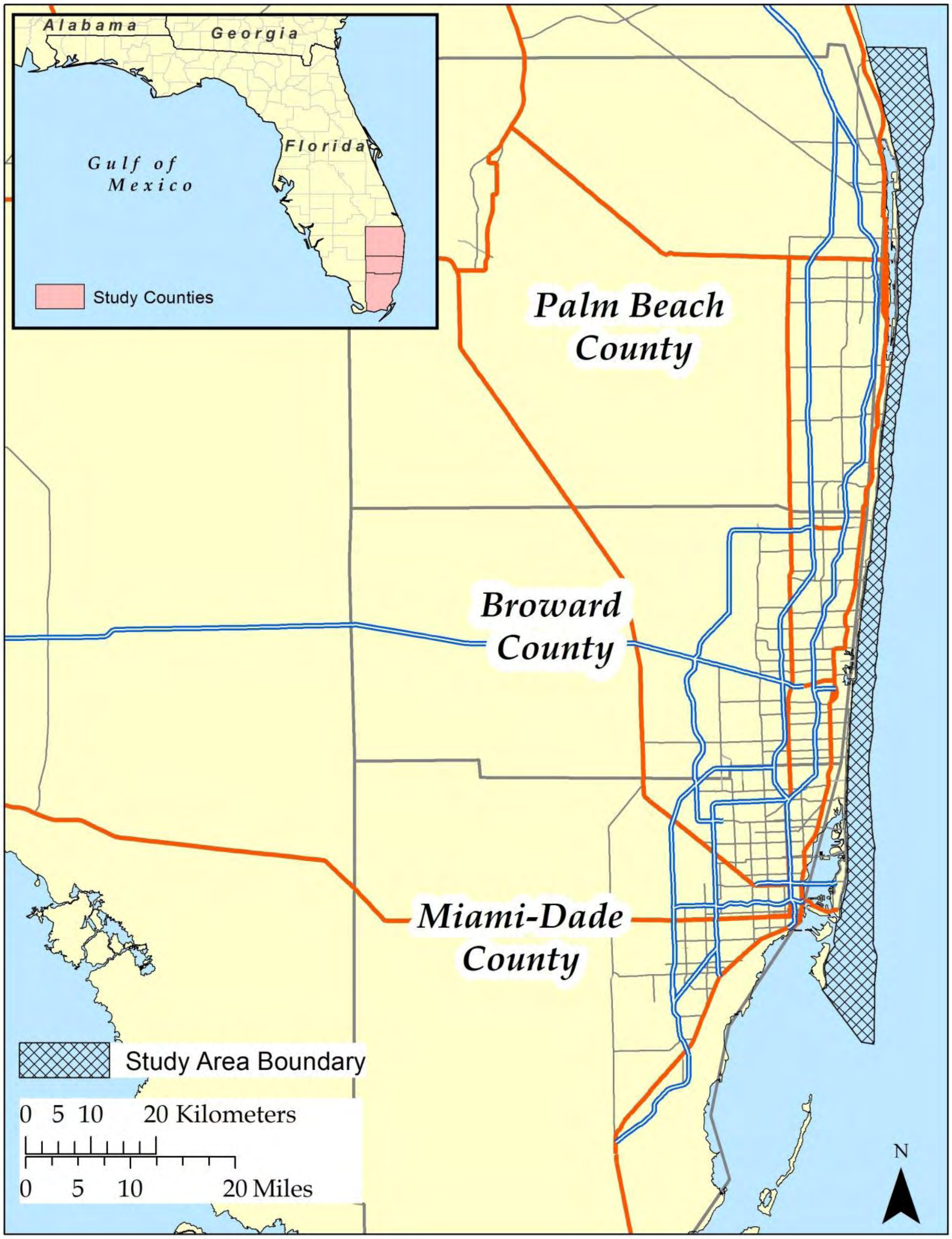


Figure 1. Study area boundaries in Miami-Dade, Broward, and Palm Beach counties.

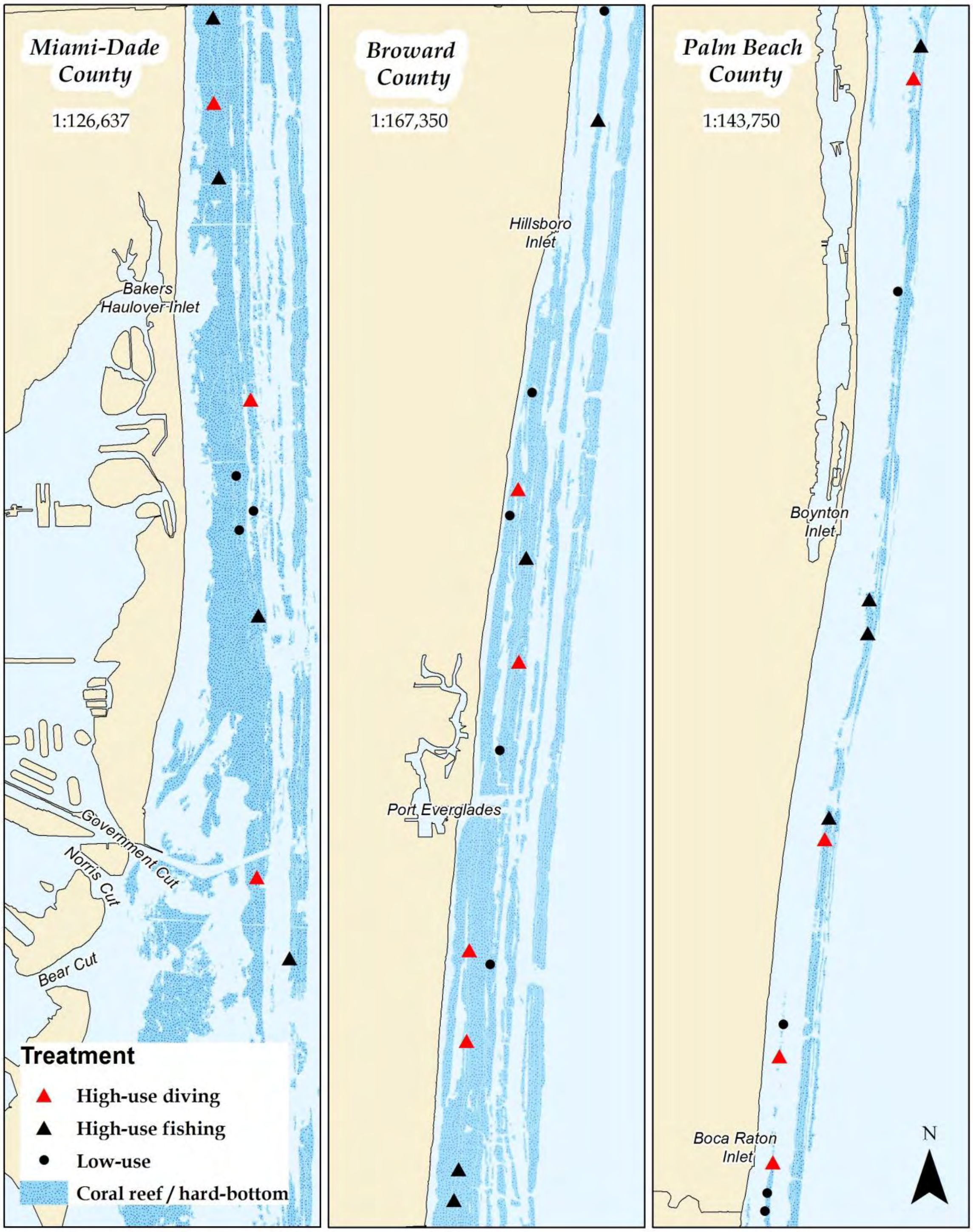


Figure 2. Site locations in Miami-Dade, Broward, and Palm Beach counties.

Table 1. Coordinates for the center of research sites in southeast Florida. Use levels are abbreviated as follows: high-use diving (HD), high-use fishing (HF), and low-use (L).

County	Site	Use level	Latitude	Longitude
Miami-Dade	M1	HD	N 25.67809	W 80.09704
Miami-Dade	M2	HD	N 25.75554	W 80.09988
Miami-Dade	M3	HD	N 25.87584	W 80.10067
Miami-Dade	M4	HD	N 25.95063	W 80.11038
Miami-Dade	M5	L	N 25.85662	W 80.10496
Miami-Dade	M6	L	N 25.84291	W 80.10419
Miami-Dade	M7	L	N 25.70811	W 80.10021
Miami-Dade	M8	HF	N 25.82141	W 80.09896
Miami-Dade	M9	HF	N 25.97211	W 80.11050
Miami-Dade	M10	HF	N 25.73505	W 80.09095
Miami-Dade	M11	HF	N 25.93185	W 80.10912
Miami-Dade	M12	L	N 25.84776	W 80.10020
Broward	B1	HF	N 25.99130	W 80.10850
Broward	B2	HD	N 26.02789	W 80.10621
Broward	B3	HF	N 25.98254	W80.10984
Broward	B4	L	N 26.04961	W 80.09949
Broward	B5	HD	N 26.05368	W 80.10541
Broward	B6	L	N 26.11067	W 80.09681
Broward	B7	HD	N 26.13593	W 80.09136
Broward	B8	HF	N 26.16546	W 80.08924
Broward	B9	L	N 26.17751	W 80.09388
Broward	B10	HD	N 26.18499	W 80.09151
Broward	B11	L	N 26.21249	W 80.08762
Broward	B12	HF	N 26.29022	W 80.06880
Palm Beach	PB1	L	N 26.32115	W 80.06703
Palm Beach	PB2	L	N 26.32725	W 80.06623
Palm Beach	PB3	HD	N 26.33742	W 80.06432
Palm Beach	PB4	HF	N 26.45170	W 80.04569
Palm Beach	PB5	HD	N 26.37252	W 80.06212
Palm Beach	PB6	HD	N 26.44452	W 80.04711
Palm Beach	PB7	HF	N 26.52403	W 80.03239
Palm Beach	PB8	HF	N 26.51289	W 80.03290
Palm Beach	PB9	L	N 26.62613	W 80.02287
Palm Beach	PB10	HD	N 26.69680	W 80.01769
Palm Beach	PB11	HF	N 26.70765	W 80.01534
Palm Beach	PB12	L	N 26.38314	W 80.06095

Table 2. Dates research sites in southeast Florida were surveyed.

Site	Year 1	Year 2	Year 3
M1	10/09/08	08/27/09	10/13/10
M2	12/02/08	11/04/09	12/15/10
M3	01/23/09	11/04/09	02/02/11
M4	10/02/08	09/02/09	10/19/10
M5	10/10/08	09/02/09	12/15/11
M6	10/08/08	09/03/09	12/15/11
M7	11/04/08	09/03/09	10/28/10
M8	11/05/08	09/03/09	10/28/10
M9	10/01/08	09/02/09	10/19/10
M10	12/02/08	11/04/09	12/15/11
M11	10/10/08	08/27/09	10/13/10
M12	11/06/08	09/03/09	10/27/10
B1	02/12/09	01/29/10	02/03/11
B2	02/12/09	01/29/10	02/02/11
B3	04/16/09	02/19/10	02/02/11
B4	03/19/09	01/29/10	02/26/11
B5	04/02/09	02/20/10	02/26/11
B6	03/31/09	02/20/10	02/26/11
B7	04/01/09	02/20/10	02/26/11
B8	04/01/09	03/24/10	02/27/11
B9	04/01/09	03/25/10	02/27/11
B10	04/16/09	03/25/10	02/27/11
B11	04/15/09	03/24/10	02/28/11
B12	07/29/09	05/19/10	02/28/11
PB1	05/13/09	04/27/10	03/24/11
PB2	05/13/09	04/27/10	03/24/11
PB3	06/02/09	04/28/10	03/24/11
PB4	06/03/09	04/27/10	04/02/11
PB5	06/24/09	04/27/10	04/02/11
PB6	07/02/09	05/19/10	03/29/11
PB7	06/04/09	05/19/10	04/03/11
PB8	06/25/09	05/19/10	04/02/11
PB9	06/30/09	06/09/10	03/02/11
PB10	07/28/09	06/10/10	04/07/11
PB11	07/28/09	06/11/10	04/07/11
PB12	07/30/09	05/19/10	03/25/11

3.3 Site design

Each site consisted of four 1 x 25 m belt transects, oriented in the four cardinal directions. Wider transects would have required too much diver bottom-time to be completed safely. The center of each site and the transect ends were delineated with rebar stakes hammered into pre-drilled holes in non-living reef framework (Fig. 3). Transect surveys began 1 m from the center stake to avoid transect overlap.

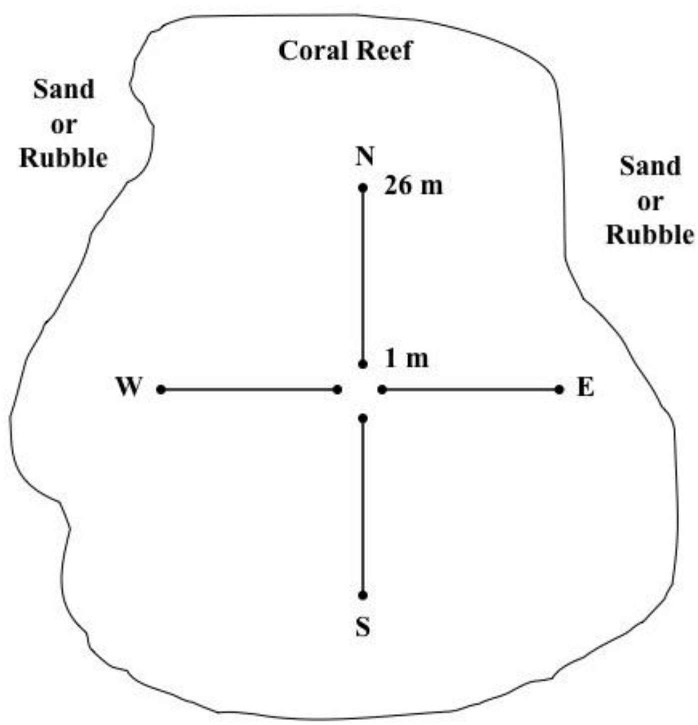


Figure 3. Site survey design showing four 25 m transects in the cardinal directions. Transects were set in the cardinal directions to cover a large area of reef while increasing relocation ease for subsequent surveys.

3.4 Site characterization

Along each transect a diver performed a species inventory using a 1 m PVC pole marked in the center. The position (to within 0.1 m) along the transect of all corals and sponges (> 0.1 m in any dimension) within the belt transect were recorded. The only exception was for gorgonians, other than sea fans (*Gorgonia ventalina*), which were too numerous to map in a reasonable time frame while maintaining diver safety. These were only tallied for each transect unless they were damaged. Organisms were identified down to the lowest possible taxonomic level, typically to species. The percentage of live tissue compared to bare skeleton, bleaching, or disease was also recorded for each organism observed.

A second diver used a point-intercept line transect method to measure the benthic coverage along each transect. Categories of benthic coverage included any patches > 0.1 m (Table 3), and was simply a description of the type of benthic substrate or living organism covering it. The rugosity of each reef site was also measured using a 20 m weighted plastic chain that was laid out along each transect and pushed down into depressions in the substrate. From this the rugosity index was calculated as a ratio of the distance the chain covered to its actual length. The depth at the beginning and end of each transect was also measured. Sessile organisms, benthic cover, rugosity, and depth were measured to control for differences between sites and included in the analysis as covariates as necessary. The point-intercept line transect was not meant as an absolute measure of live coral coverage, but used as a relative measure between sites.

Table 3. Benthic coverage types and abbreviations used in site characterization.

Benthic cover types	Abbreviation
Live Coral	LC
New Dead Coral (clean)	NDC
Old Dead Coral (colonized)	ODC
Zooanthid Mat	PALY
Sponge	SPO
Boring Sponge	SPC
Fleshy Macroalgae	MAF
Calcareous Macroalgae	MAC
Rubble	R
Sand	S
Pavement	P

3.5 Damage assessments

Transects were evaluated for impacts including damaged organisms, dislodged organisms, and debris (e.g., monofilament, commercial lobster trap gear, trash, etc.). Coral bleaching and disease were also recorded to examine any associations between these conditions and reef use or activity.

During each site survey all sessile organisms within the belt transects that showed signs of injury were marked with a numbered plastic cattle ear tag attached to the adjacent substrate with a masonry nail. Dislodged sessile organisms (e.g., hard corals, gorgonians, and sponges) were marked and measured, but otherwise left undisturbed. In subsequent surveys we measured the distance moved by dislodged organisms and the reattachment status (reattached or remaining dislodged). Corals (Smith and Hughes 1999) and sponges (Wulff 1995) are both capable of reattachment, with some species of sponges reattaching within weeks depending on sediment depth and turbulence (Butler and Behringer unpublished data). Each marked individual was then photographed and the dimensions of the injury measured and recorded (if possible). Upon each successive survey any new injuries were treated in this way and previously marked injuries were re-photographed and re-measured.

3.6 Recovery assessment

The original design of the experiment called for quantitative measurement of damage, including number of organisms damaged and the dimensions of the injuries. Recovery was to be measured as area of a wound healed in subsequent years. However, during field assessments it became apparent that dimensions of most injuries would not be quantifiable due to the nature of the injuries, such as dislodgement or broken (and missing) branches from branching corals. We therefore chose to rank the recovery of damaged organisms using the images taken each year and a standard scale (Table 4). The status of a damaged organism was qualitatively ranked using visual observation of the images taken each additional year that it was observed. That is, a damaged organism marked and photographed in year 1 was re-photographed and recovery assessed in years 2 and 3, but a damaged organism originally observed in year 2 would only be re-assessed in year 3. Each set of photographs was ranked by two separate investigators and any descrepancies were addressed and a common rank selected.

Table 4. Ranking scale used to determine the recovery status of damaged organisms.

Ranking	Scale
-4	100% decline
-3	75% decline
-2	50% decline
-1	25% decline
0	No change or healed over but no tissue replaced
1	25 % recovered
2	50 % recovered
3	75% recovered
4	100% recovered
5	missing

3.7 Statistical analysis

The damage data was organized into three categories for analysis: a) hard corals combined with barrel sponges *Xestospongia muta*, b) gorgonians only, and c) all damage combined (hard corals, gorgonians, and *X. muta*). The hard corals and *X. muta* were combined because *X. muta* showed the effects of damage similar to hard corals (e.g., gouges, breaks, dislodgement). Moreover, it was very difficult to decern damage in any other sponge species as they often grow amorphously and appear to recover rapidly.

3.7.1 Analysis of year 1 – instantaneous damage assessment by use level and county

For all three damage categories, instantaneous (year 1 only) damage was modeled as the number of organisms damaged divided by total number of organisms counted, combined over all transects. This was considered instantaneous damage because it included cumulative damage to the time of the first survey, regardless of when it occurred. Use level, county, and the use level by county interaction factors were used as the predictors. The data were binomial so a logistic regression was used. After the results of the model were analyzed it was determined that data were over-dispersed, therefore a scale parameter was used to correct the standard errors of the means and the means comparisons.

3.7.2 Analysis of yearly damage by use level and county

Year 1 damage was the culmination of all identifiable damage to that time, but the damage observed in years 2 and 3 presumably occurred since the previous survey. We used a repeated-measures linear mixed model to determine if differences existed in the mean percent of "new"damage between years, use levels, and counties. All three damage categories were analyzed separately.

3.7.3 Analysis of recovery

This analysis combined all of the damage data to enhance replication and the likelihood of accurately determining if differences existed. To analyze the recovery of damaged organisms between years, use levels, and counties, two repeated-measures linear mixed model analyses were performed. The first analyzed the mean recovery rank of damaged organisms observed initially in year 1 and assessed in year 2 and those observed initially in year 2 and assessed in year 3. The organisms observed initially in year 1 were not included in the year 3 assessment here because we did not know the approximate date of their injury. Many of these organisms may have already recovered to the extent possible and this would bias the results if they were combined with year 2 damage assessed in year 3. The second analysis focused only on the assessment in year 3, but included damaged organisms first observed in year 1 and 2. This analysis was used to determine if the rate of recovery changed with time. That is, did organisms recover more rapidly soon after injury.

3.7.4 Analysis of marine debris

A repeated-measures linear mixed model was used to determine if differences in the abundance of marine debris existed between years, use levels, and counties. The debris counts were square root transformed to meet the linear model assumptions. Debris did not move enough within the transects to permit analysis of movement.

4.0 Results

4.1 Year 1 – Instantaneous damage assessment by use level and county

4.1.1 Hard corals and barrel sponges combined

Instantaneous damage refers to the measure of all visible damage in year 1, so is the culmination of all damage to date that remained identifiable. The mean percentage of hard corals and barrel sponges damaged on all sites was < 10.4%, ranging from 2.0% on Broward County high fishing sites to 10.3% on Miami-Dade County low use sites (Table 5). There were no differences between any of the use level treatments (Table 6-8) (Fig. 4). The mean percentage of hard corals and barrel sponges damaged by county ranged from 2.5% in Palm Beach to 7.6% in Miami-Dade (Table 9-11). There was a significantly higher percentage of hard corals and barrel sponges damaged in Miami-Dade (7.58%) than either Broward (3.09%) ($P = 0.0336$) or Palm Beach (2.45%) ($P = 0.0047$) (Table 11) (Fig. 4). Table 12 shows the mean and standard error of the mean for all of the use level by county combinations.

Table 5. Percentage of each organism type damaged by county and use level (percentage of the total number of each). Use levels are abbreviated as follows: high-use diving (HD), high-use fishing (HF), and low-use (L). Percentages are back-transformed least squares means.

County	Use level	Hard coral + Barrel sponge damage	Gorgonian damage	All damage
Broward	HD	6.3%	3.9%	4.3%
Broward	HF	2.0%	1.7%	1.8%
Broward	L	2.4%	2.9%	2.8%
Palm Beach	HD	2.0%	3.6%	3.3%
Palm Beach	HF	2.2%	1.6%	1.7%
Palm Beach	L	3.3%	5.0%	4.5%
Miami-Dade	HD	5.2%	4.0%	4.3%
Miami-Dade	HF	8.1%	5.4%	6.1%
Miami-Dade	L	10.3%	6.3%	7.1%

Table 6. Percentage of organisms damaged by use level as a percentage of the total number per use level. Use levels are abbreviated as follows: high-use diving (HD), high-use fishing (HF), and low-use (L). Percentages are back-transformed least squares means.

Use level	Hard coral + Barrel sponge damage	Gorgonian damage	All damage
HD	4.1%	3.8%	3.9%
HF	3.3%	2.5%	2.7%
L	4.4%	4.5%	4.5%

Table 7. Year 1 least squares means by use level for number of hard corals and barrel sponges damaged per site as a percentage of the total number of hard corals and barrel sponges on each site. Year 1 damage includes all cumulative damage until the time of the first survey.

Use level	Estimate	Standard Error	df	t Value	Pr > |t|	Mean	Standard Error Mean
HD	-3.1650	0.2759	27	-11.47	<0.0001	0.04051	0.01072
HF	-3.3703	0.2283	27	-14.76	<0.0001	0.03324	0.007336
L	-3.0908	0.2788	27	-11.09	<0.0001	0.04349	0.01160

Table 8. Year 1 differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) of hard coral and barrel sponge damage between use levels. Year 1 damage includes all cumulative damage until the time of the first survey.

Use level	Use level	Estimate	Standard Error	df	t Value	Pr > |t|	Adj P
HD	HF	0.2053	0.3581	27	0.57	0.5712	0.8354
HD	L	-0.07417	0.3922	27	-0.19	0.8514	0.9805
HF	L	-0.2795	0.3603	27	-0.78	0.4447	0.7209

Table 9. Percentage of organisms damaged by county as a percentage of the total number per county. Percentages are back-transformed least squares means.

County	Hard coral + Barrel sponge damage	Gorgonian damage	All damage
Broward	3.1%	2.7%	3.9%
Palm Beach	2.5%	3.1%	2.9%
Miami-Dade	7.6%	5.1%	5.7%

Table 10. Year 1 least squares means by county for number of hard corals and barrel sponges damaged per site as a percentage of the total number of hard corals and barrel sponges on each site. Year 1 damage includes all cumulative damage until the time of the first survey. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale.

County	Estimate	Standard Error	df	t Value	Pr > |t|	Mean	Standard Error Mean
Broward	-3.4440	0.3011	27	-11.44	<0.0001	0.03095	0.009031
Miami-Dade	-2.5003	0.1876	27	-13.33	<0.0001	0.07584	0.01315
Palm Beach	-3.6818	0.2830	27	-13.01	<0.0001	0.02456	0.006780

Table 11. Year 1 differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) of hard coral and barrel sponge damage between counties. Year 1 damage includes all cumulative damage until the time of the first survey.

County	County	Estimate	Standard Error	df	t Value	Pr > |t|	Adj P
Broward	Miami-Dade	-0.9437	0.3548	27	-2.66	0.0130	0.0336‡
Broward	Palm Beach	0.2378	0.4132	27	0.58	0.5698	0.8343
Miami-Dade	Palm Beach	1.1814	0.3395	27	3.48	0.0017	0.0047‡

‡Denotes a significant result at $\alpha = 0.05$.

Table 12. Year 1 least squares means by use level*county interaction for number of hard corals and barrel sponges damaged per site as a percentage of the total number of hard corals and barrel sponges on each site. Year 1 damage includes all cumulative damage until the time of the first survey. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale.

Use level	County	Estimate	Standard Error	df	t Value	Pr > |t|	Mean	Standard Error Mean
HD	Broward	-2.7081	0.4671	27	-5.80	<0.0001	0.06250	0.02737
HD	Miami-Dade	-2.9079	0.3571	27	-8.14	<0.0001	0.05176	0.01753
HD	Palm Beach	-3.8790	0.5825	27	-6.66	<0.0001	0.02025	0.01156
HF	Broward	-3.8965	0.4569	27	-8.53	<0.0001	0.01991	0.008914
HF	Miami-Dade	-2.4259	0.3008	27	-8.07	<0.0001	0.08122	0.02244
HF	Palm Beach	-3.7884	0.4123	27	-9.19	<0.0001	0.02213	0.008922
L	Broward	-3.7274	0.6238	27	-5.98	<0.0001	0.02349	0.01431
L	Miami-Dade	-2.1671	0.3143	27	-6.89	<0.0001	0.1027	0.02898
L	Palm Beach	-3.3779	0.4600	27	-7.34	<0.0001	0.03299	0.01468

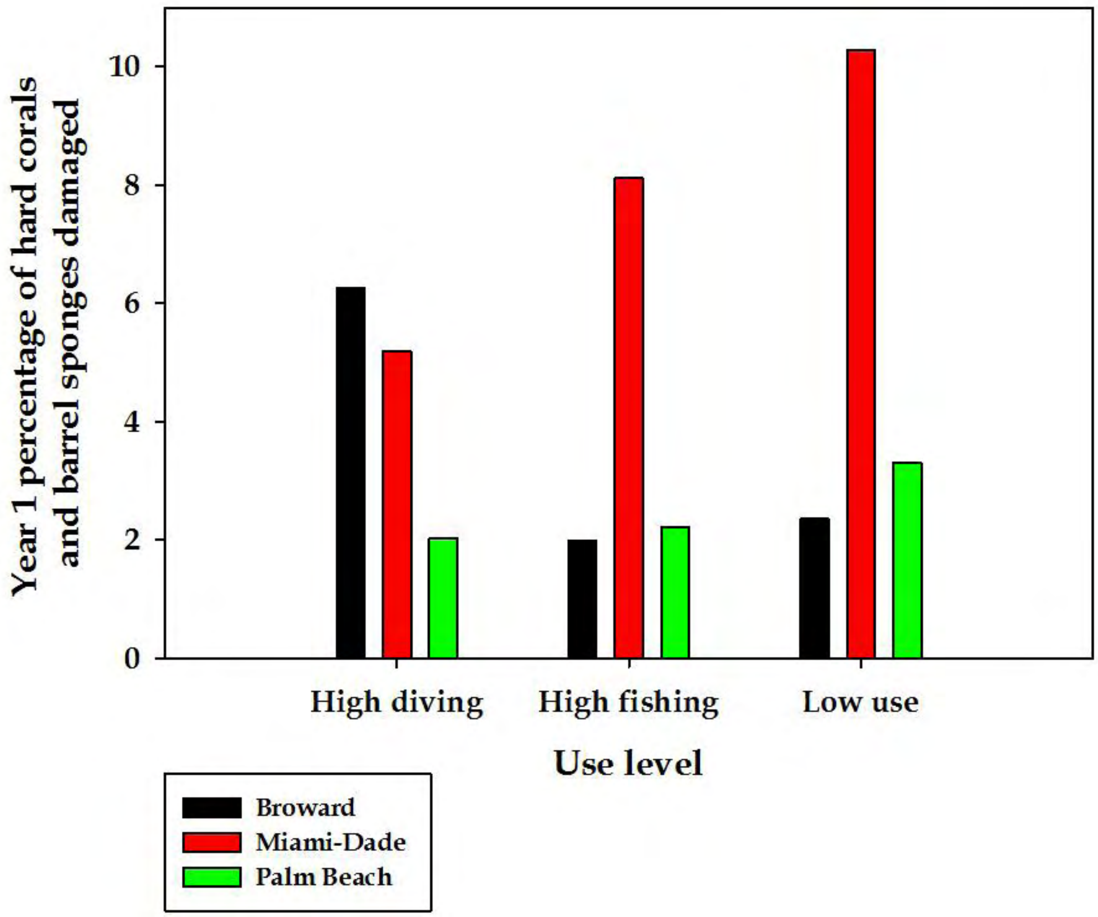


Figure 4. Year 1 percentage of hard corals and barrel sponges damaged (percentage of the total number of hard corals and barrel sponges) as a function of use level and southeast Florida county.

4.1.2 Gorgonians only

The mean percentage of gorgonians damaged on all sites was < 6.3%, ranging from 1.6% on Palm Beach County high fishing sites to 6.3% on Miami-Dade County low use sites (Table 5). The mean percentage of gorgonians damaged on low use sites was significantly higher (4.51%) than that on high fishing sites (2.44%), although only marginally so (P = 0.0489) (Table 6, 13, 14) (Fig. 5). The mean percentage of gorgonians damaged by county ranged from 2.7% in Broward to 5.1% in Miami-Dade (Table 9, 15). There was a significantly higher percentage of gorgonians damaged in Miami-Dade (5.14%) than Broward (2.68%) (P = 0.0343) (Table 16) (Fig. 5). Table 17 shows the mean and standard error of the mean for all of the use level by county combinations.

Table 13. Year 1 least squares means by use level for number of gorgonians damaged per site as a percentage of the total number of gorgonians on each site. Year 1 damage includes all cumulative damage until the time of the first survey. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale.

Use level	Estimate	Standard Error	df	t Value	Pr > |t|	Mean	Standard Error Mean
HD	-3.2251	0.1756	27	-18.36	<.0001	0.03823	0.006458
HF	-3.6865	0.1902	27	-19.38	<.0001	0.02445	0.004536
L	-3.0531	0.1689	27	-18.07	<.0001	0.04509	0.007274

Table 14. Year 1 differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) of gorgonian damage between use levels. Year 1 damage includes all cumulative damage until the time of the first survey.

Use level	Use level	Estimate	Standard Error	df	t Value	Pr > |t|	Adj P
HD	HF	0.4613	0.2589	27	1.78	0.0860	0.1946
HD	L	-0.1721	0.2437	27	-0.71	0.4862	0.7620
HF	L	-0.6334	0.2544	27	-2.49	0.0192	0.0489‡

‡Denotes a significant result at $\alpha = 0.05$.

Table 15. Year 1 least squares means by county for number of gorgonians damaged per site as a percentage of the total number of gorgonians on each site. Year 1 damage includes all cumulative damage until the time of the first survey. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale.

County	Estimate	Standard Error	df	t Value	Pr > |t|	Mean	Standard Error Mean
Broward	-3.5921	0.2032	27	-17.68	<0.0001	0.02680	0.005299
Miami-Dade	-2.9147	0.1550	27	-18.81	<0.0001	0.05143	0.007561
Palm Beach	-3.4578	0.1740	27	-19.87	<0.0001	0.03054	0.005151

Table 16. Year 1 differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) of gorgonian damage between counties. Year 1 damage includes all cumulative damage until the time of the first survey.

County	County	Estimate	Standard Error	df	t Value	Pr > |t|	Adj P
Broward	Miami-Dade	-0.6774	0.2555	27	-2.65	0.0133	0.0343‡
Broward	Palm Beach	-0.1343	0.2675	27	-0.50	0.6196	0.8709
Miami-Dade	Palm Beach	0.5431	0.2330	27	2.33	0.0275	0.0684

‡Denotes a significant result at $\alpha = 0.05$.

Table 17. Year 1 least squares means by use level*county interaction for number of gorgonians damaged per site as a percentage of the total number of gorgonians on each site. Year 1 damage includes all cumulative damage until the time of the first survey. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale.

Use level	County	Estimate	Standard Error	df	t Value	Pr > |t|	Mean	Standard Error Mean
HD	Broward	-3.2158	0.3451	27	-9.32	<0.0001	0.03858	0.01280
HD	Miami-Dade	-3.1819	0.2935	27	-10.84	<0.0001	0.03985	0.01123
HD	Palm Beach	-3.2777	0.2691	27	-12.18	<0.0001	0.03634	0.009424
HF	Broward	-4.0418	0.4028	27	-10.03	<0.0001	0.01726	0.006834
HF	Miami-Dade	-2.8688	0.2694	27	-10.65	<0.0001	0.05372	0.01370
HF	Palm Beach	-4.1488	0.3012	27	-13.77	<0.0001	0.01554	0.004607
L	Broward	-3.5188	0.3003	27	-11.72	<0.0001	0.02878	0.008393
L	Miami-Dade	-2.6935	0.2397	27	-11.24	<0.0001	0.06336	0.01422
L	Palm Beach	-2.9469	0.3306	27	-8.91	<0.0001	0.04988	0.01567

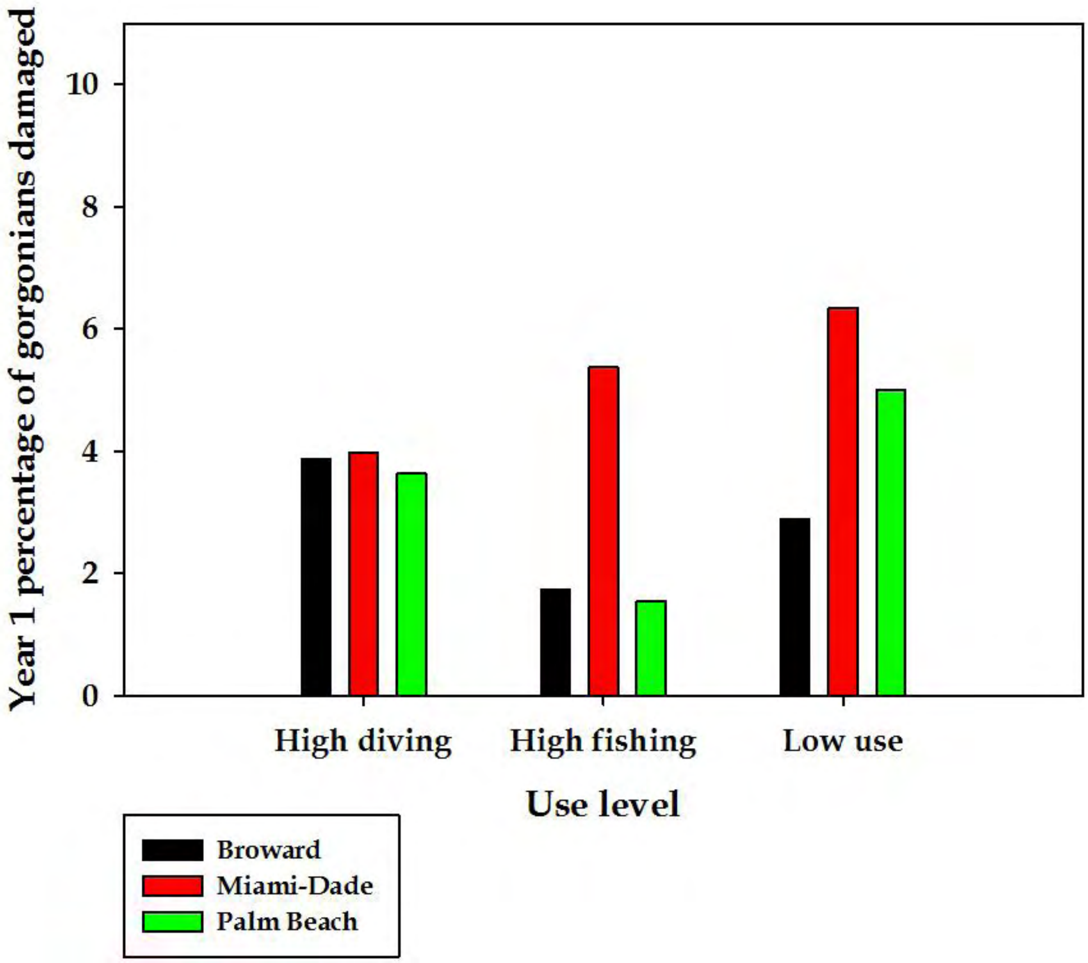


Figure 5. Year 1 percentage of gorgonians damaged (percentage of the total number of gorgonians), by use level and southeast Florida county.

4.1.3 Total damage for hard corals, barrel sponges, and gorgonians combined

The mean percentage of all organisms damaged on all sites was < 7.2%, ranging from 1.7% on Palm Beach County high fishing sites to 7.1% on Miami-Dade low use sites (Table 5). There were no differences between any of the use level treatments (Table 6, 18, 19) (Fig. 6). The mean percentage of all organisms damaged by county ranged from 2.8% in Broward to 5.7% in Miami-Dade (Table 9, 20). There was a significantly higher percentage of all organisms damaged in Miami-Dade (5.67%) than either Broward (2.78%) (P = 0.0150) or Palm Beach (2.93%) (P = 0.0141) (Table 21) (Fig. 6). Table 22 shows the mean and standard error of the mean for all of the use level by county combinations.

Table 18. Year 1 least squares means by use level for number of all damaged organisms combined per site as a percentage of the total number of all damaged organisms combined on each site. Year 1 damage includes all cumulative damage until the time of the first survey. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale.

Use level	Estimate	Standard Error	df	t Value	Pr > |t|	Mean	Standard Error Mean
HD	-3.1954	0.1736	27	-18.40	<0.0001	0.03934	0.006562
HF	-3.6046	0.1790	27	-20.14	<0.0001	0.02648	0.004614
L	-3.0632	0.1695	27	-18.07	<0.0001	0.04465	0.007232

Table 19. Year 1 differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) of all damaged organisms combined, between use levels. Year 1 damage includes all cumulative damage until the time of the first survey.

Use level	Use level	Estimate	Standard Error	df	t Value	Pr > |t|	Adj P
HD	HF	0.4092	0.2494	27	1.64	0.1125	0.2464
HD	L	-0.1322	0.2427	27	-0.54	0.5903	0.8499
HF	L	-0.5414	0.2465	27	-2.20	0.0369	0.0900

Table 20. Year 1 least squares means by county for number of all damaged organisms combined per site as a percentage of the total number of all damaged organisms combined on each site. Year 1 damage includes all cumulative damage until the time of the first survey. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale.

County	Estimate	Standard Error	df	t Value	Pr > |t|	Mean	Standard Error Mean
Broward	-3.5518	0.1980	27	-17.94	<0.0001	0.02787	0.005365
Miami-Dade	-2.8105	0.1464	27	-19.20	<0.0001	0.05676	0.007835
Palm Beach	-3.5009	0.1741	27	-20.11	<0.0001	0.02929	0.004950

Table 21. Year 1 differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) for all damaged organisms combined, between counties. Year 1 damage includes all cumulative damage until the time of the first survey.

County	County	Estimate	Standard Error	df	t Value	Pr > |t|	Adj P
Broward	Miami-Dade	-0.7412	0.2462	27	-3.01	0.0056	0.0150‡
Broward	Palm Beach	-0.05087	0.2637	27	-0.19	0.8484	0.9797
Miami-Dade	Palm Beach	0.6904	0.2275	27	3.04	0.0053	0.0141‡

‡Denotes a significant result at $\alpha = 0.05$.

Table 22. Year 1 least squares means by use level*county interaction for number of all organisms damaged per site as a percentage of the total number of all damaged organisms combined on each site. Year 1 damage includes all cumulative damage until the time of the first survey. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale.

Use level	County	Estimate	Standard Error	df	t Value	Pr > |t|	Mean	Standard Error Mean
HD	Broward	-3.1109	0.3363	27	-9.25	<0.0001	0.04266	0.01373
HD	Miami-Dade	-3.1100	0.2782	27	-11.18	<0.0001	0.04270	0.01137
HD	Palm Beach	-3.3654	0.2844	27	-11.83	<0.0001	0.03340	0.009181
HF	Broward	-3.9980	0.3739	27	-10.69	<0.0001	0.01802	0.006618
HF	Miami-Dade	-2.7432	0.2486	27	-11.04	<0.0001	0.06047	0.01412
HF	Palm Beach	-4.0726	0.2945	27	-13.83	<0.0001	0.01675	0.004850
L	Broward	-3.5464	0.3160	27	-11.22	<.0001	0.02802	0.008607
L	Miami-Dade	-2.5785	0.2315	27	-11.14	<.0001	0.07054	0.01518
L	Palm Beach	-3.0647	0.3244	27	-9.45	<.0001	0.04459	0.01382

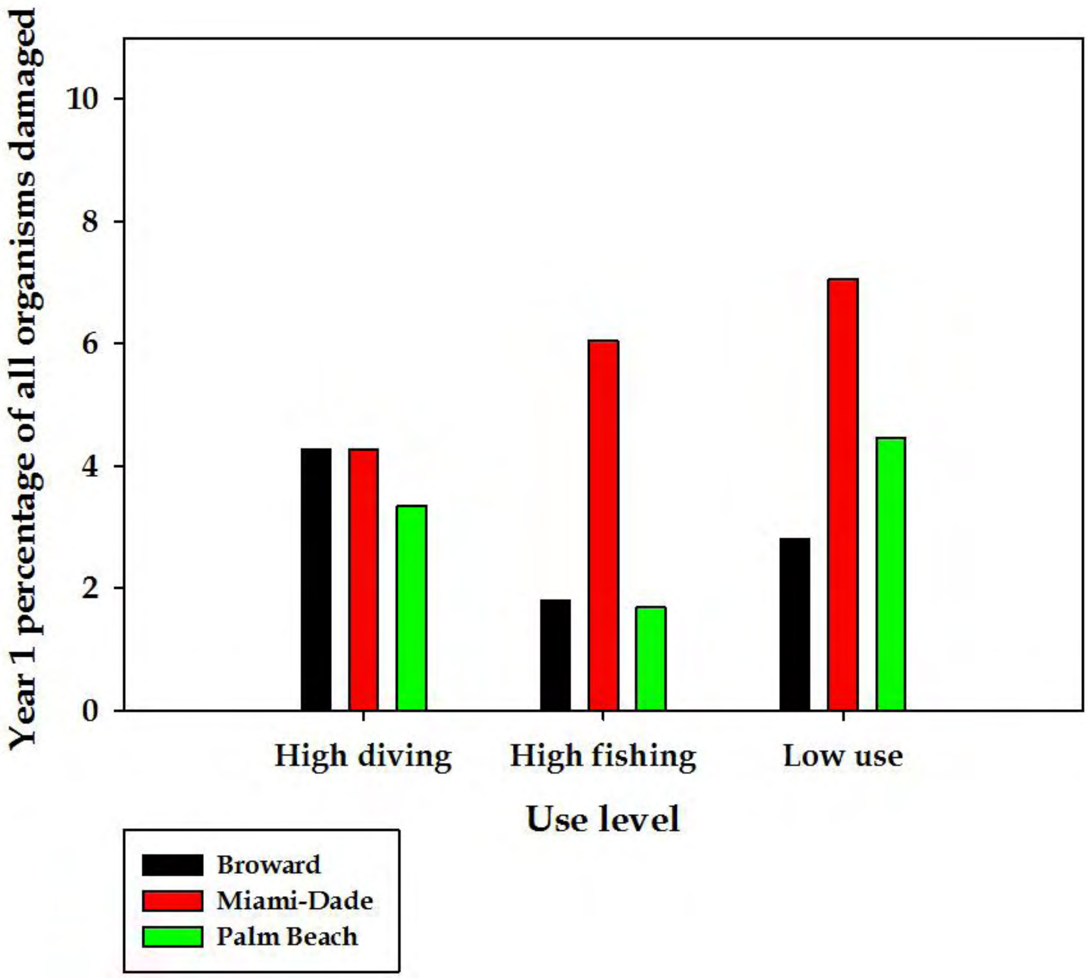


Figure 6. Year 1 percentage of all organisms damaged (percentage of the total number of all organisms), by use level and southeast Florida county.

4.2 Yearly damage by use level and county

4.2.1 Hard corals and barrel sponges combined

The percentage of hard corals and barrel sponges first observed to be damaged in year 1 (4.41%) was significantly higher than years 2 (1.36%) ($P < 0.0001$) or 3 (1.27%) ($P < 0.0001$), but years 2 and 3 did not differ ($P = 0.9618$) (Table 23, 26-28) (Fig. 7-9). There was also a greater percentage of hard corals and barrel sponges damaged in Miami-Dade county (3.01%) compared to Palm Beach county (1.35%) ($P = 0.035$) regardless of use level or year, but there was no difference between Broward county (1.89%) and either Miami-Dade county ($P = 0.3088$) or Palm Beach county ($P = 0.6063$) (Table 24, 26, 29, 30) (Fig. 7, 8). There was no effect of use level or any of the interactions (Table 25, 26).

Table 23. Percentage of each organism type damaged by county and use level (percentage of the total number of each) in years 2 and 3. Use levels are abbreviated as follows: high-use diving (HD), high-use fishing (HF), and low-use (L). Percentages are back-transformed least squares means.

County	Use level	Hard coral + Barrel sponge damage		Gorgonian damage		All damage	
		Year 2	Year 3	Year 2	Year 3	Year 2	Year 3
Broward	HD	2.4%	1.4%	4.2%	2.8%	3.9%	2.5%
Broward	HF	1.7%	1.1%	2.2%	1.4%	2.1%	1.3%
Broward	L	1.7%	0.7%	5.2%	4.3%	4.7%	3.8%
Palm Beach	HD	1.2%	0.9%	1.9%	4.1%	1.7%	3.3%
Palm Beach	HF	3.6%	2.0%	1.7%	2.2%	2.2%	2.2%
Palm Beach	L	1.0%	2.4%	0.8%	3.3%	0.9%	3.1%
Miami-Dade	HD	0.5%	1.3%	2.2%	3.7%	1.9%	3.2%
Miami-Dade	HF	1.5%	1.1%	1.0%	2.2%	1.1%	2.0%
Miami-Dade	L	0.5%	1.0%	1.6%	2.1%	1.3%	1.8%

Table 24. Percentage of organisms damaged by county as a percentage of the total number per county in years 2 and 3. Percentages are back-transformed least squares means.

County	Hard coral + Barrel sponge damage		Gorgonian damage		All damage	
	Year 2	Year 3	Year 2	Year 3	Year 2	Year 3
Broward	1.9%	1.0%	3.7%	2.5%	3.4%	2.3%
Palm Beach	1.6%	1.7%	1.4%	3.1%	1.5%	2.8%
Miami-Dade	0.7%	1.1%	1.5%	2.6%	1.4%	2.3%

Table 25. Percentage of organisms damaged by use level as a percentage of the total number per use level in years 2 and 3. Use levels are abbreviated as follows: high-use diving (HD), high-use fishing (HF), and low-use (L). Percentages are back-transformed least squares means.

Use level	Hard coral + Barrel sponge damage		Gorgonian damage		All damage	
	Year 2	Year 3	Year 2	Year 3	Year 2	Year 3
HD	1.1%	1.2%	2.6%	3.5%	2.3%	3.0%
HF	2.1%	1.3%	1.6%	1.9%	1.7%	1.8%
L	1.0%	1.2%	1.9%	3.1%	1.8%	2.8%

Table 26. Results of a repeated-measures linear mixed model analysis of the effects of year, use level, and county on the percentage of hard corals and barrel sponges damaged per site as a percentage of the total number of hard corals and barrel sponges on each site.

Effect	Num df	Den df	F Value	Pr > F
Year	2	50.76	22.78	<0.0001‡
County	2	35.24	3.37	0.0458‡
County*Year	4	55.02	1.42	0.2395
Use level	2	30.65	0.32	0.7304
Use level*Year	4	55.46	0.69	0.6043
County*Use level	4	41.57	1.33	0.2753

‡Denotes a significant result at $\alpha = 0.05$.

Table 27. Least squares means by year for the percentage of hard corals and barrel sponges damaged per site as a percentage of the total number of hard corals and barrel sponges on each site. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale.

Year	Estimate	Standard Error	df	t Value	Pr > |t|	Mean	Standard Error Mean
1	-3.0772	0.1378	31.31	-22.32	<0.0001	0.04406	0.005806
2	-4.2873	0.2656	30.66	-16.14	<0.0001	0.01356	0.003551
3	-4.3559	0.1725	28.6	-25.25	<0.0001	0.01267	0.002158

Table 28. Differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) for the percentage of hard corals and barrel sponges damaged, between years.

Year	Year	Estimate	Standard Error	df	t Value	Pr > |t|	Adj P
1	2	1.2102	0.2497	39.78	4.85	<0.0001	<0.0001‡
1	3	1.2787	0.2056	55.7	6.22	<0.0001	<0.0001‡
2	3	0.06855	0.2576	45.38	0.27	0.7914	0.9618

‡Denotes a significant result at $\alpha = 0.05$.

Table 29. Least squares means by county for the percentage of hard corals and barrel sponges damaged per site as a percentage of the total number of hard corals and barrel sponges on each site. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale.

County	Estimate	Standard Error	df	t Value	Pr > |t|	Mean	Standard Error Mean
Broward	-3.9525	0.2549	33.41	-15.51	<0.0001	0.01885	0.004713
Miami-Dade	-3.4736	0.2066	32.22	-16.82	<0.0001	0.03007	0.006025
Palm Beach	-4.2943	0.2573	34.11	-16.69	<0.0001	0.01346	0.003417

Table 30. Differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) for the percentage of hard corals and barrel sponges damaged, between counties.

County	County	Estimate	Standard Error	df	t Value	Pr > |t|	Adj P
Broward	Miami-Dade	-0.4789	0.3218	34.94	-1.49	0.1457	0.3088
Broward	Palm Beach	0.3418	0.3559	35.87	0.96	0.3433	0.6063
Miami-Dade	Palm Beach	0.8207	0.3231	35.07	2.54	0.0157	0.0405‡

‡Denotes a significant result at $\alpha = 0.05$.

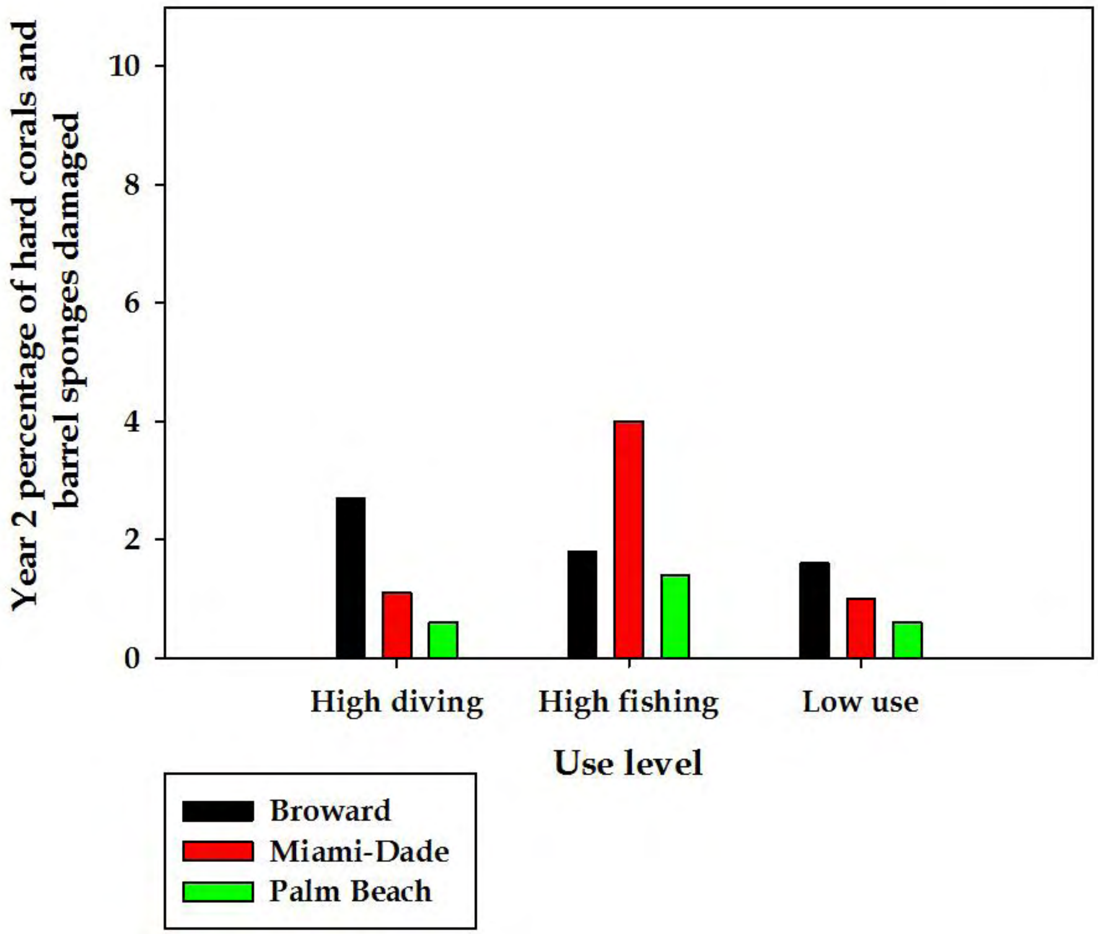


Figure 7. Year 2 percentage of hard corals and barrel sponges damaged (percentage of the total number of hard corals and barrel sponges), by use level and southeast Florida county.

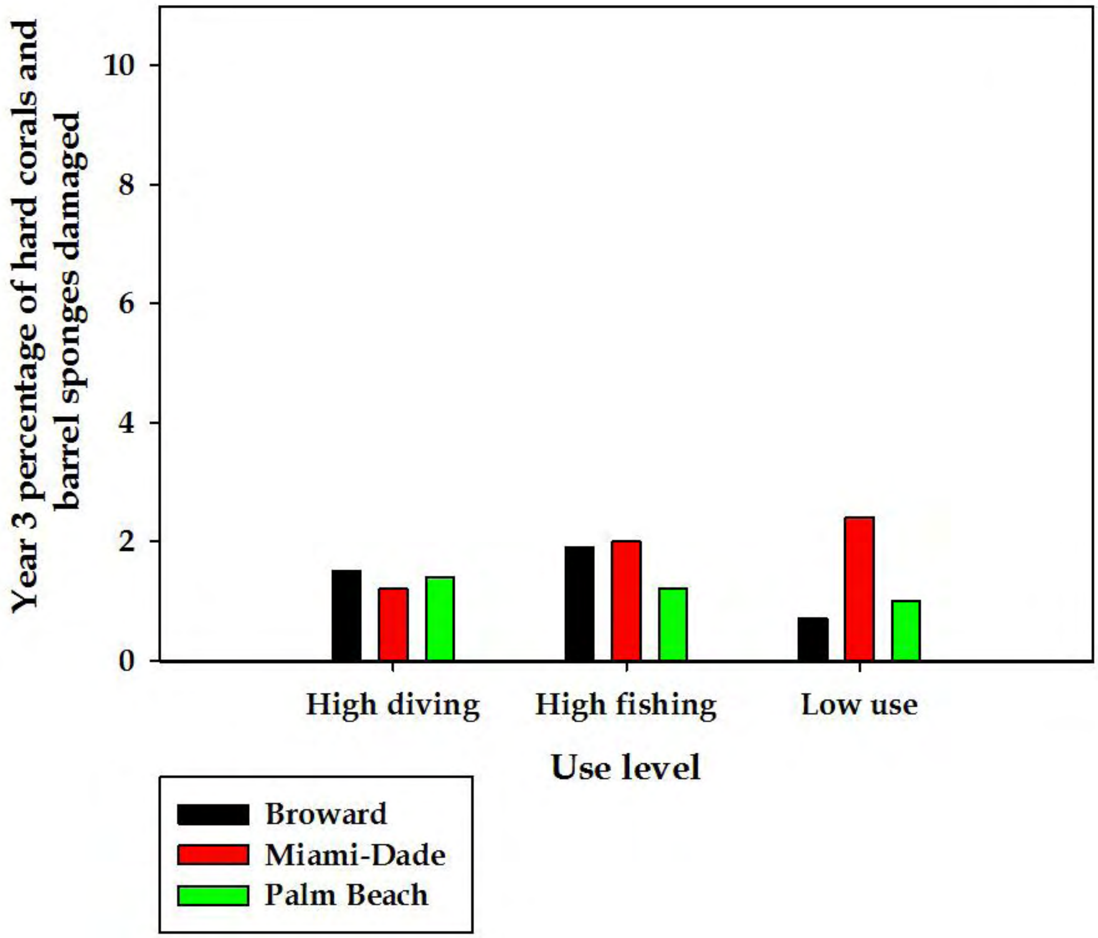


Figure 8. Year 3 percentage of hard corals and barrel sponges damaged (percentage of the total number of hard corals and barrel sponges), by use level and southeast Florida county.

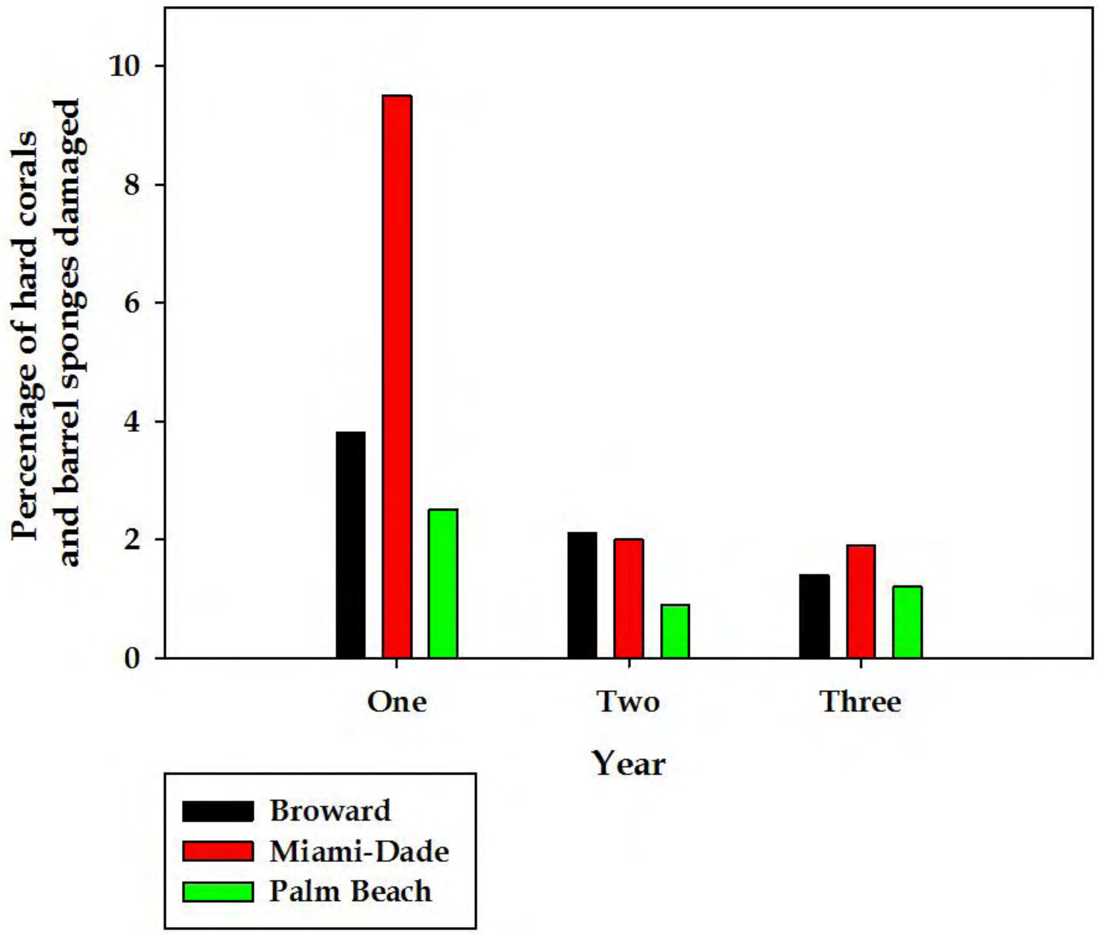


Figure 9. Yearly percentage of hard corals and barrel sponges damaged (percentage of the total number of hard corals and barrel sponges), by southeast Florida county.

4.2.2 Gorgonians only

The percentage of gorgonians first observed to be damaged in year 1 (3.30%) was significantly higher than year 2 (2.02%) (P = 0.0047), but was not different than year 3 (2.88%) (P = 0.6358), but year 2 was also significantly lower than year 3 (P = 0.0391) (Table 23, 31-33) (Fig. 10-12). There was no effect of county (Table 24, 31, 34, 35). However, there was a county*year interaction, with Miami-Dade County having a significantly greater percentage of gorgonians damaged in year 1 (5.19%) than Broward County (2.45%) (P = 0.0308) (Table 36-38) (Fig. 10-12). Broward County had a greater percentage damaged in year 2 (3.70%) than either Miami-Dade County (1.5%) (P = 0.0192) or Palm Beach County (1.47%) (P = 0.0089). No other interactions were significant. There was also a greater percentage of gorgonians damaged on high diving sites (3.11%) and low use sites (3.21%) compared to high fishing sites (1.92%) (P = 0.0500 and P = 0.0418, respectively) regardless of year or county, but there was no difference between low use sites and high diving sites (P = 0.9844) (Table 25, 39, 40) (Fig. 10, 11).

Table 31. Results of a repeated-measures linear mixed model analysis of the effects of year, use level, and county on the percentage of gorgonians damaged per site as a percentage of the total number of gorgonians on each site.

Effect	Num df	Den df	F Value	Pr > F
Year	2	48.82	6.04	0.0045‡
County	2	30.84	1.00	0.3798
County*Year	4	53.43	6.39	0.0003‡
Use level	2	33.9	4.08	0.0258‡
Use level*Year	4	53.9	0.28	0.8837
County*Us level	4	35.37	0.80	0.8873

‡Denotes a significant result at $\alpha = 0.05$.

Table 32. Least squares means by year for the percentage of gorgonians damaged per site as a percentage of the total number of gorgonians on each site. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale.

Year	Estimate	Standard Error	df	t Value	Pr > |t|	Mean	Standard Error Mean
1	-3.3781	0.1209	29.99	-27.93	<0.0001	0.03299	0.003858
2	-3.8831	0.1368	30.88	-28.38	<0.0001	0.02017	0.002704
3	-3.5169	0.1094	29.45	-32.14	<0.0001	0.02884	0.003065

‡Denotes a significant result at $\alpha = 0.05$.

Table 33. Differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) for the percentage of gorgonians damaged, between years.

Year	Year	Estimate	Standard Error	df	t Value	Pr > |t|	Adj P
1	2	0.5050	0.1517	46.84	3.33	0.0017	0.0047‡
1	3	0.1388	0.1523	58.64	0.91	0.3659	0.6358
2	3	-0.3662	0.1452	45.4	-2.52	0.0152	0.0391‡

Table 34. Least squares means by county for the percentage of gorgonians damaged per site as a percentage of the total number of gorgonians on each site. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale.

County	Estimate	Standard Error	df	t Value	Pr > |t|	Mean	Standard Error Mean
Broward	-3.5119	0.1460	31.6	-24.06	<0.0001	0.02898	0.004107
Miami-Dade	-3.4988	0.1526	28.96	-22.93	<0.0001	0.02935	0.004346
Palm Beach	-3.7674	0.1533	31.34	-24.58	<0.0001	0.02259	0.003385

Table 35. Differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) for the percentage of gorgonians damaged, between counties.

County	County	Estimate	Standard Error	df	t Value	Pr > |t|	Adj P
Broward	Miami-Dade	-0.01314	0.2111	30.64	-0.06	0.9508	0.9979
Broward	Palm Beach	0.2555	0.2105	31.62	1.21	0.2339	0.4543
Miami-Dade	Palm Beach	0.2687	0.2161	30.28	1.24	0.2233	0.4374

Table 36. Least squares means by county*year interaction for the percentage of gorgonians damaged per site as a percentage of the total number of gorgonians on each site. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale.

County	Year	Estimate	Standard Error	df	t Value	Pr > |t|	Mean	Standard Error Mean
Broward	1	-3.6850	0.2426	30.68	-15.19	<0.0001	0.02448	0.005793
Broward	2	-3.2593	0.1759	29.81	-18.53	<0.0001	0.03700	0.006268
Broward	3	-3.5915	0.2001	29.44	-17.95	<0.0001	0.02682	0.005221
Miami-Dade	1	-2.9059	0.1766	28.21	-16.45	<0.0001	0.05186	0.008685
Miami-Dade	2	-4.1845	0.2799	29.57	-14.95	<0.0001	0.01500	0.004136
Miami-Dade	3	-3.4059	0.1893	28.04	-18.00	<0.0001	0.03211	0.005883
Palm Beach	1	-3.5435	0.2090	29.34	-16.96	<0.0001	0.02810	0.005708
Palm Beach	2	-4.2055	0.2471	32.32	-17.02	<0.0001	0.01469	0.003578
Palm Beach	3	-3.5533	0.1818	29.67	-19.54	<0.0001	0.02783	0.004920

Table 37. Tests of the county*year interaction effect by year for the percentage of gorgonians damaged per site as a percentage of the total number of gorgonians on each site.

Year	Num df	Den df	F Value	Pr > F
1	2	29.39	4.50	0.0197‡
2	2	30.36	6.60	0.0042‡
3	2	28.84	0.26	0.7700

‡Denotes a significant result at $\alpha = 0.05$.

Table 38. Least squares means simple effect comparison of the county*year interaction by year for the percentage of gorgonians damaged per site as a percentage of the total number of gorgonians on each site.

Year	County	County	Estimate	Standard Error	df	t Value	Pr > |t|	Adj P
1	Broward	Miami-Dade	-0.7791	0.2983	30.19	-2.61	0.0139	0.0308‡
1	Broward	Palm Beach	-0.1415	0.3243	29.5	-0.44	0.6657	0.9005
1	Miami-Dade	Palm Beach	0.6376	0.2745	28.62	2.32	0.0275	0.0612
2	Broward	Miami-Dade	0.9253	0.3306	29.65	2.80	0.0089	0.0192‡
2	Broward	Palm Beach	0.9463	0.3069	30.8	3.08	0.0043	0.0089‡
2	Miami-Dade	Palm Beach	0.02098	0.3731	30.75	0.06	0.9555	0.9983
3	Broward	Miami-Dade	-0.1856	0.2747	28.93	-0.68	0.5046	0.7786
3	Broward	Palm Beach	-0.03817	0.2728	28.85	-0.14	0.8897	0.9893
3	Miami-Dade	Palm Beach	0.1474	0.2628	28.75	0.56	0.5791	0.8412

‡Denotes a significant result at $\alpha = 0.05$.

Table 39. Least squares means by use level for the percentage of gorgonians damaged per site as a percentage of the total number of gorgonians on each site. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale.

Use level	Estimate	Standard Error	df	t Value	Pr > |t|	Mean	Standard Error Mean
HD	-3.4392	0.1386	31.88	-24.81	<0.0001	0.03109	0.004176
HF	-3.9336	0.1501	32.06	-26.21	<0.0001	0.01920	0.002826
L	-3.4053	0.1506	34.32	-22.61	<0.0001	0.03213	0.004683

Table 40. Differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) for the percentage of gorgonians damaged, between use levels.

Use level	Use level	Estimate	Standard Error	df	t Value	Pr > |t|	Adj P
HD	HF	0.4944	0.2017	32.72	2.45	0.0198	0.0500‡
HD	L	-0.03397	0.2008	34.63	-0.17	0.8666	0.9844
HF	L	-0.5284	0.2088	34.44	-2.53	0.0161	0.0418‡

‡Denotes a significant result at $\alpha = 0.05$.

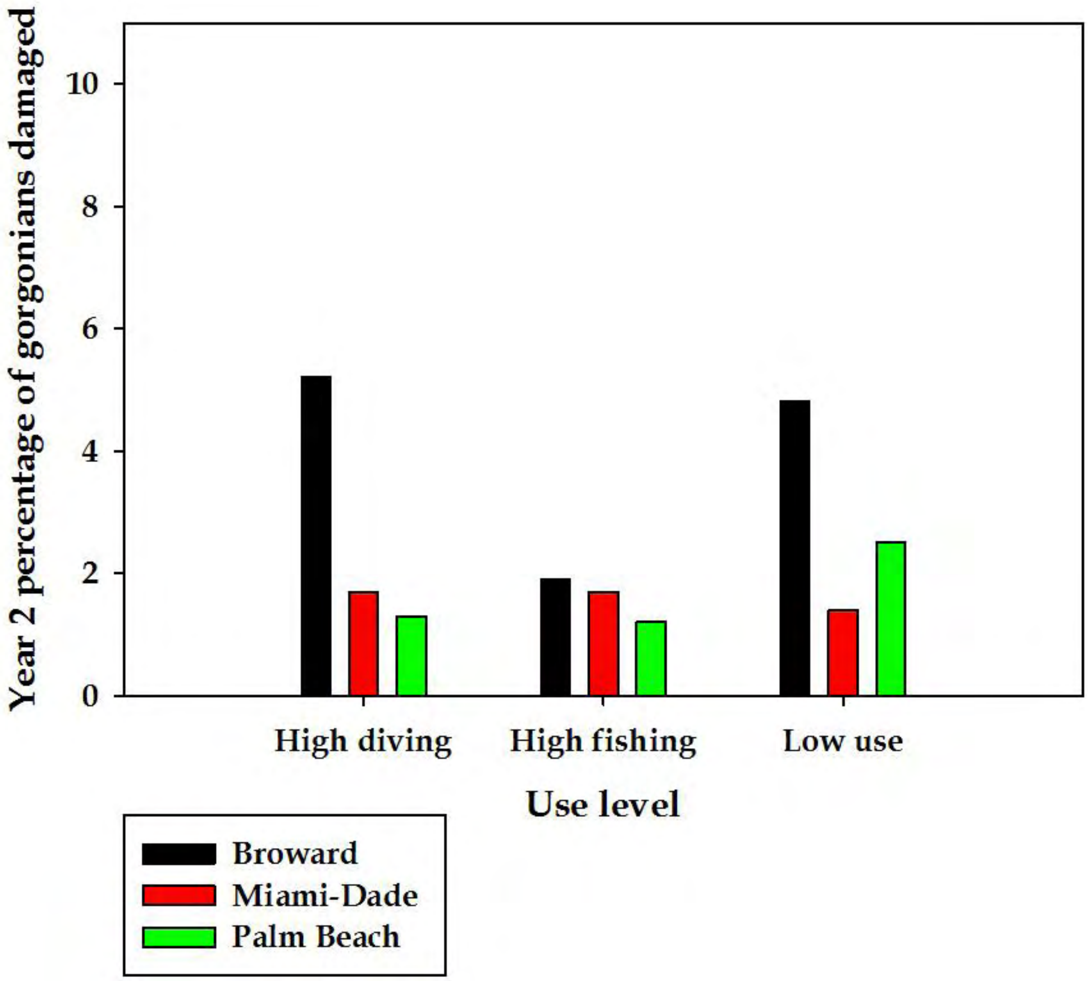


Figure 10. Year 2 percentage of gorgonians damaged (percentage of the total number of gorgonians), by use level and southeast Florida county.

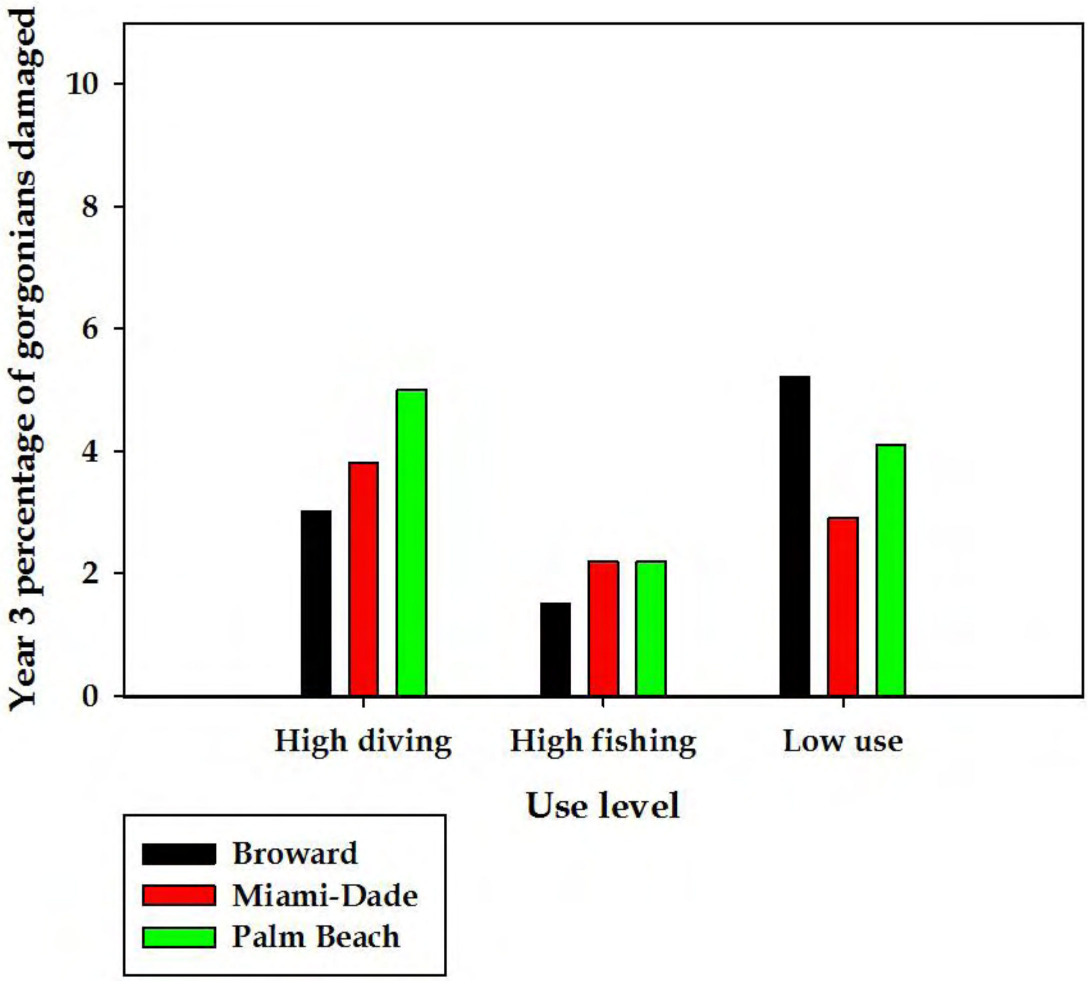


Figure 11. Year 3 percentage of gorgonians damaged (percentage of the total number of gorgonians), by use level and southeast Florida county.

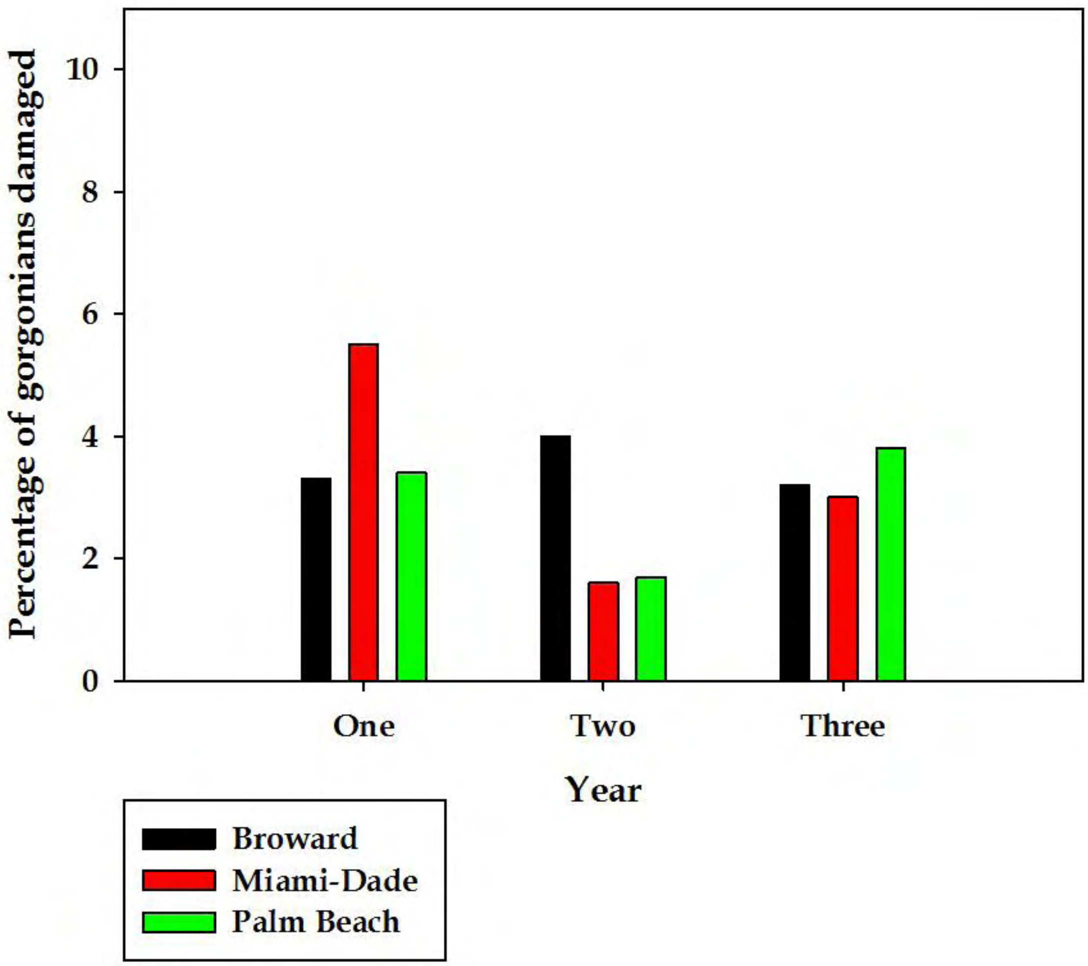


Figure 12. Yearly percentage of gorgonians damaged (percentage of the total number of gorgonians), by southeast Florida county.

4.2.3 Total damage for hard corals, barrel sponges, and gorgonians combined

Similar to hard corals and barrel sponges, the percentage of all damaged organisms first observed to be damaged in year 1 (3.57%) was significantly higher than year 2 (1.96%) (P = 0.0004) but not year 3 (2.57%) (P = 0.0505). Years 2 and 3 did not differ (P = 0.1383) (Table 23, 41-43) (Fig. 13-15). There was no effect of county (Table 24, 41, 44, 45). However, there was a county*year interaction, with Miami-Dade County having a significantly greater percentage of gorgonians damaged in year 1 (6.01%) than Broward County (2.78%) (P = 0.0094) or Palm Beach County (2.70%) (P = 0.0043) (Table 46-48) (Fig. 13-15). Broward County had a greater percentage damaged in year 2 (3.44%) than either Miami-Dade County (1.61%) (P = 0.0463) or Palm Beach County (1.34%) (P = 0.0082). Use level was not a significant factor, nor were any of the other interactions (Table 25, 41).

Table 41. Results of a repeated-measures linear mixed model analysis of the effects of year, use level, and county on the percentage of all organisms damaged per site as a percentage of the total number of organisms on each site.

Effect	Num df	Den df	F Value	Pr > F
Year	2	48.67	8.61	0.0006‡
County	2	31.02	2.33	0.1144
County*Year	4	53.39	6.00	0.0005‡
Use level	2	33.04	2.95	0.0662
Use level*Year	4	53.84	0.32	0.8655
County*Use level	4	36.83	1.21	0.3245

‡Denotes a significant result at $\alpha = 0.05$.

Table 42. Least squares means by use level for the percentage of all organisms damaged per site as a percentage of all organisms on each site. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale.

Year	Estimate	Standard Error	df	t Value	Pr > |t|	Mean	Standard Error Mean
1	-3.2967	0.1089	29.82	-30.28	<0.0001	0.03568	0.003747
2	-3.9147	0.1336	30.83	-29.30	<0.0001	0.01956	0.002562
3	-3.6362	0.09945	28.25	-36.56	<0.0001	0.02568	0.002488

Table 43. Differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) for the percentage of all organisms damaged, between years.

Year	Year	Estimate	Standard Error	df	t Value	Pr > |t|	Adj P
1	2	0.6179	0.1485	44.34	4.16	0.0001	0.0004‡
1	3	0.3394	0.1407	58.46	2.41	0.0190	0.0505
2	3	-0.2785	0.1435	44.57	-1.94	0.0587	0.1383

‡Denotes a significant result at $\alpha = 0.05$.

Table 44. Least squares means by county for the percentage of all organisms damaged per site as a percentage of all organisms on each site. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale.

County	Estimate	Standard Error	df	t Value	Pr > |t|	Mean	Standard Error Mean
Broward	-3.5305	0.1306	31.74	-27.04	<0.0001	0.02846	0.003610
Miami-Dade	-3.4584	0.1354	28.93	-25.53	<0.0001	0.03052	0.004007
Palm Beach	-3.8587	0.1433	31.78	-26.93	<0.0001	0.02066	0.002899

Table 45. Differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) for the percentage of all organisms damaged, between counties.

County	County	Estimate	Standard Error	df	t Value	Pr > |t|	Adj P
Broward	Miami-Dade	-0.07204	0.1880	30.71	-0.38	0.7042	0.9225
Broward	Palm Beach	0.3282	0.1932	31.82	1.70	0.0991	0.2217
Miami-Dade	Palm Beach	0.4002	0.1969	30.58	2.03	0.0508	0.1212

Table 46. Least squares means by county*year interaction for the percentage of all organisms damaged per site as a percentage of all organisms on each site. The estimate column values are the means on the logit scale and the mean column values are back-transformed means to the proportional scale.

County	Year	Estimate	Standard Error	df	t Value	Pr > |t|	Mean	Standard Error Mean
Broward	1	-3.5565	0.2146	29.88	-16.57	<0.0001	0.02775	0.005789
Broward	2	-3.3360	0.1770	29.84	-18.84	<0.0001	0.03436	0.005873
Broward	3	-3.6989	0.1820	28.19	-20.32	<0.0001	0.02415	0.004290
Miami-Dade	1	-2.7501	0.1531	28.34	-17.96	<0.0001	0.06008	0.008645
Miami-Dade	2	-4.1112	0.2627	29.67	-15.65	<0.0001	0.01612	0.004167
Miami-Dade	3	-3.5140	0.1709	27.19	-20.56	<0.0001	0.02892	0.004800
Palm Beach	1	-3.5836	0.1969	29.73	-18.20	<0.0001	0.02703	0.005177
Palm Beach	2	-4.2968	0.2486	31.99	-17.28	<0.0001	0.01343	0.003294
Palm Beach	3	-3.6956	0.1655	28.44	-22.33	<0.0001	0.02423	0.003913

Table 47. Tests of the county*year interaction effect by year for the percentage of all organisms damaged per site as a percentage of the total number of gorgonians on each site.

Year	Num df	Den df	F Value	Pr > F
1	2	29.31	7.66	0.0021‡
2	2	30.36	5.96	0.0066‡
3	2	27.78	0.38	0.6864

‡Denotes a significant result at $\alpha = 0.05$.

Table 48. Least squares means simple effect comparison of the county*year interaction by year for the percentage of all organisms damaged per site as a percentage of all organisms on each site.

Year	County	County	Estimate	Standard Error	df	t Value	Pr > |t|	Adj P
1	Broward	Miami-Dade	-0.8064	0.2630	29.51	-3.07	0.0046	0.0094‡
1	Broward	Palm Beach	0.02706	0.2941	29.35	0.09	0.9273	0.9953
1	Miami-Dade	Palm Beach	0.8335	0.2498	29.09	3.34	0.0023	0.0043‡
2	Broward	Miami-Dade	0.7752	0.3172	29.67	2.44	0.0207	0.0463‡
2	Broward	Palm Beach	0.9608	0.3083	30.79	3.12	0.0039	0.0082‡
2	Miami-Dade	Palm Beach	0.1855	0.3608	30.77	0.51	0.6107	0.8647
3	Broward	Miami-Dade	-0.1849	0.2493	27.8	-0.74	0.4644	0.7398
3	Broward	Palm Beach	-0.00329	0.2477	27.8	-0.01	0.9895	0.9999
3	Miami-Dade	Palm Beach	0.1816	0.2381	27.74	0.76	0.4520	0.7273

‡Denotes a significant result at $\alpha = 0.05$.

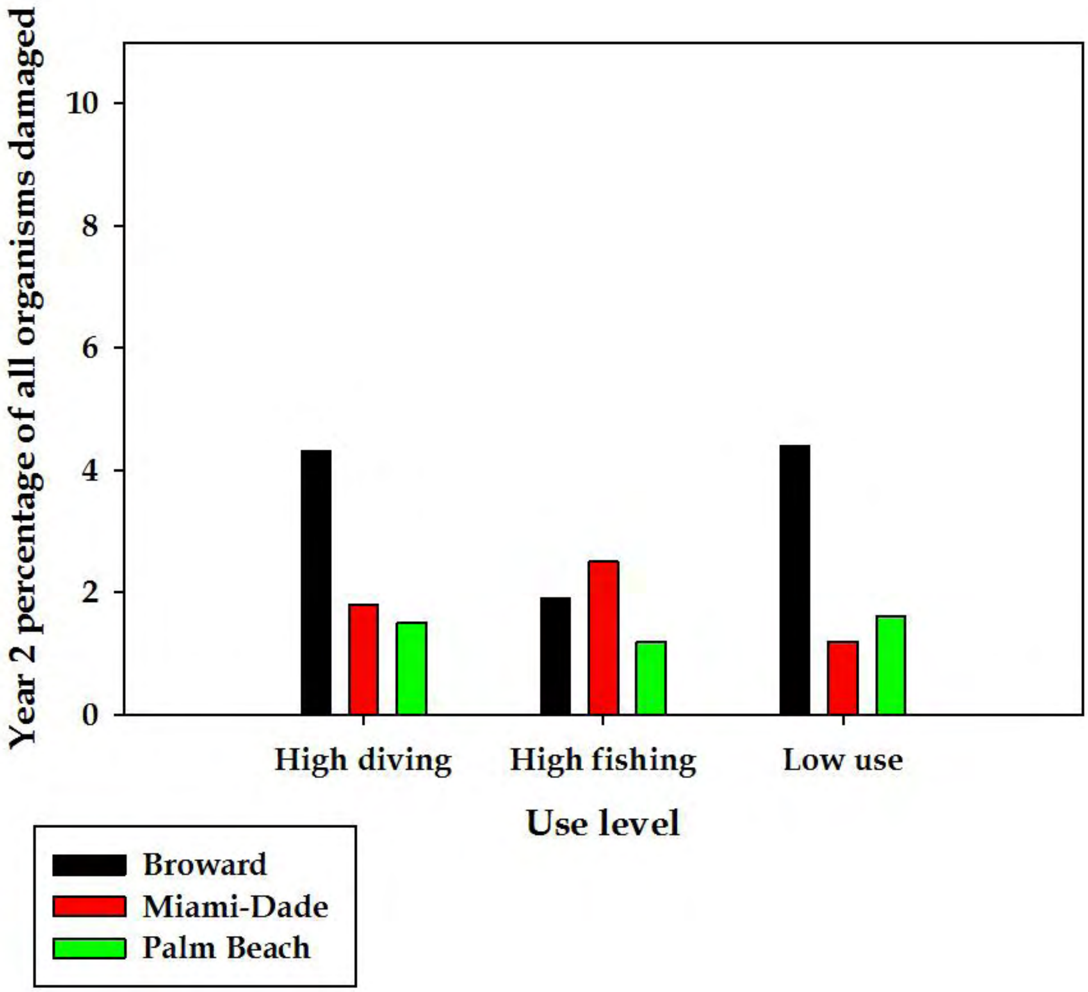


Figure 13. Year 2 percentage of all organisms damaged (percentage of the total number of all organisms), by use level and southeast Florida county.

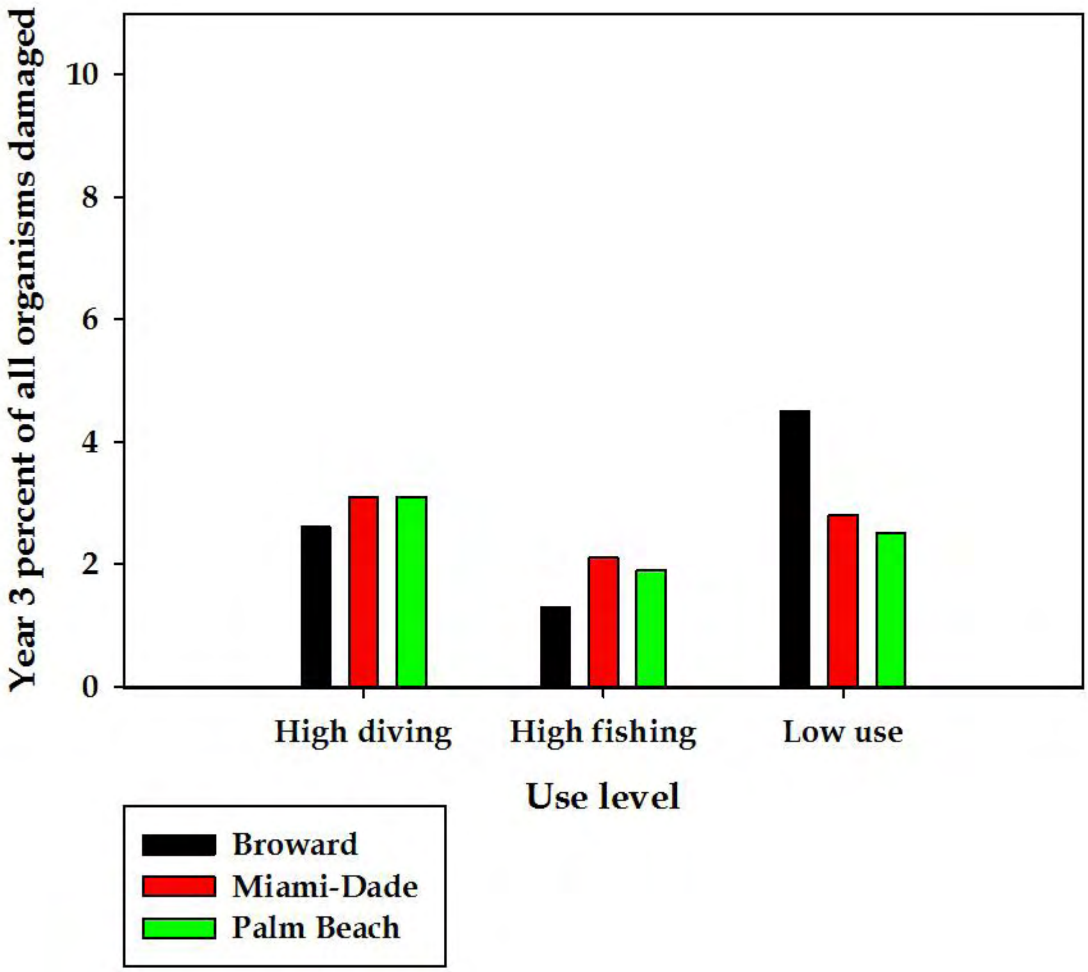


Figure 14. Year 3 percentage of all organisms damaged (percentage of the total number of all organisms), by use level and southeast Florida county.

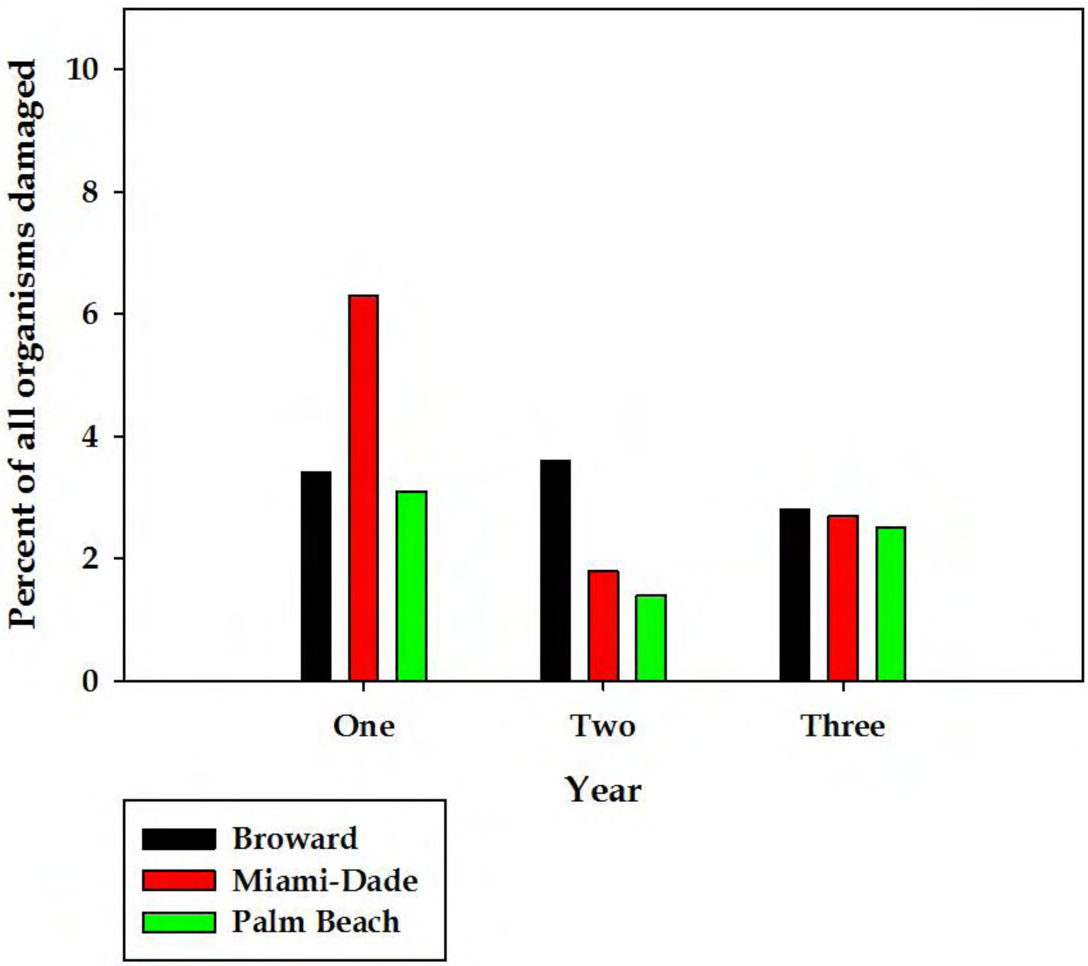


Figure 15. Yearly percentage of all organisms damaged (percentage of the total number of all organisms), by southeast Florida county.

4.3 Recovery

4.3.1 Recovery of year 1 versus year 2 damage

There was no difference between use levels (P = 0.5735) in the mean recovery rank of damaged organisms first observed in year 1 (all damage to that date) and assessed in year 2, and those first observed in years 1+2 (all damage) and assessed in year 3 (Table 49, 50) (Fig. 16, 17). There were also no significant interactions between model terms. However, in this comparison the effect of county was significant (P = 0.0327) (Table 49) and least squares means multiple comparison tests revealed that damaged organisms observed in Palm Beach County were significantly more degraded than Miami-Dade County (P = 0.0388) (Table 51), regardless of when they were damaged (no county*year interaction). The effect of year assessed was significant, with damaged organisms first observed in years 1+2 and assessed in year 3 significantly higher (less negative) in mean recovery rank than those first observed in year 1 and assessed in year 2 (P = 0.0343) (Table 49, 50) (Fig. 16, 17). However, the mean recovery rank of all use level, county, and year combinations was negative, indicating organisms tended to decline following damage (Fig. 16, 17).

Table 49. Repeated-measures linear model of the effect of use level and county on the recovery rank of all damaged organisms (first observed in year 1 and 2) and assessed in year 3. Year denotes year damage was first observed.

Effect	Num DF	Den DF	F Value	Pr > F
County	2	18.6	4.13	0.0327‡
Use level	2	19.9	0.57	0.5735
County*Use level	4	16	1.36	0.2919
Year	1	38.9	4.81	0.0343‡
County*Year	2	28.1	0.25	0.7792
Use level*Year	2	27.7	0.92	0.4120

‡Denotes a significant result at $\alpha = 0.05$.

Table 50. Least squares means of the recovery rank of all damaged organisms (first observed in year 1 and 2) and assessed in year 3 by year first observed (year), use level, and county.

Effect	County	Usage	Year	Estimate	Standard Error	df	t Value	Pr > |t|
County	Broward			-1.6731	0.1529	16.6	-10.94	<0.0001
County	Miami-Dade			-1.2974	0.1128	12.7	-11.50	<0.0001
County	Palm Beach			-1.8668	0.1807	7.22	-10.33	<0.0001
Use level		HD		-1.6678	0.1221	14.4	-13.66	<0.0001
Use level		HF		-1.4954	0.1218	11.4	-12.28	<0.0001
Use level		L		-1.6740	0.1957	9.31	-8.55	<0.0001
County*Use level	Broward	HD		-1.7420	0.1995	6.93	-8.73	<0.0001
County*Use level	Broward	HF		-1.3119	0.2091	6.84	-6.27	0.0005
County*Use level	Broward	L		-1.9653	0.3420	7.29	-5.75	0.0006
County*Use level	Miami-Dade	HD		-1.4566	0.2782	6.51	-5.24	0.0015
County*Use level	Miami-Dade	HF		-1.3797	0.1187	6.18	-11.62	<0.0001
County*Use level	Miami-Dade	L		-1.0560	0.1508	6.32	-7.00	0.0003
County*Use level	Palm Beach	HD		-1.8047	0.1194	5.18	-15.12	<0.0001
County*Use level	Palm Beach	HF		-1.7948	0.2724	4.52	-6.59	0.0018
County*Use level	Palm Beach	L		-2.0007	0.4535	3.95	-4.41	0.0119
Year			1	-1.7850	0.1269	38.4	-14.06	<0.0001
Year			2	-1.4398	0.1072	31.8	-13.43	<0.0001

Table 51. Differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) for the recovery rank of damaged organisms first observed in year 1 and assessed in year 3, and damaged organisms observed in year 2 and assessed in year 3.

Effect	County	County	Estimate	Standard Error	df	t Value	Pr > |t|	Adjust	Adj P
County	Broward	Miami-Dade	-0.3756	0.1902	28.5	-1.97	0.0580	Tukey-Kramer	0.1463
County	Broward	Palm Beach	0.1937	0.2369	17.2	0.82	0.4248	Tukey-Kramer	0.6971
County	Miami-Dade	Palm Beach	0.5693	0.2132	12.8	2.67	0.0195	Tukey-Kramer	0.0388‡

‡Denotes a significant result at $\alpha = 0.05$.

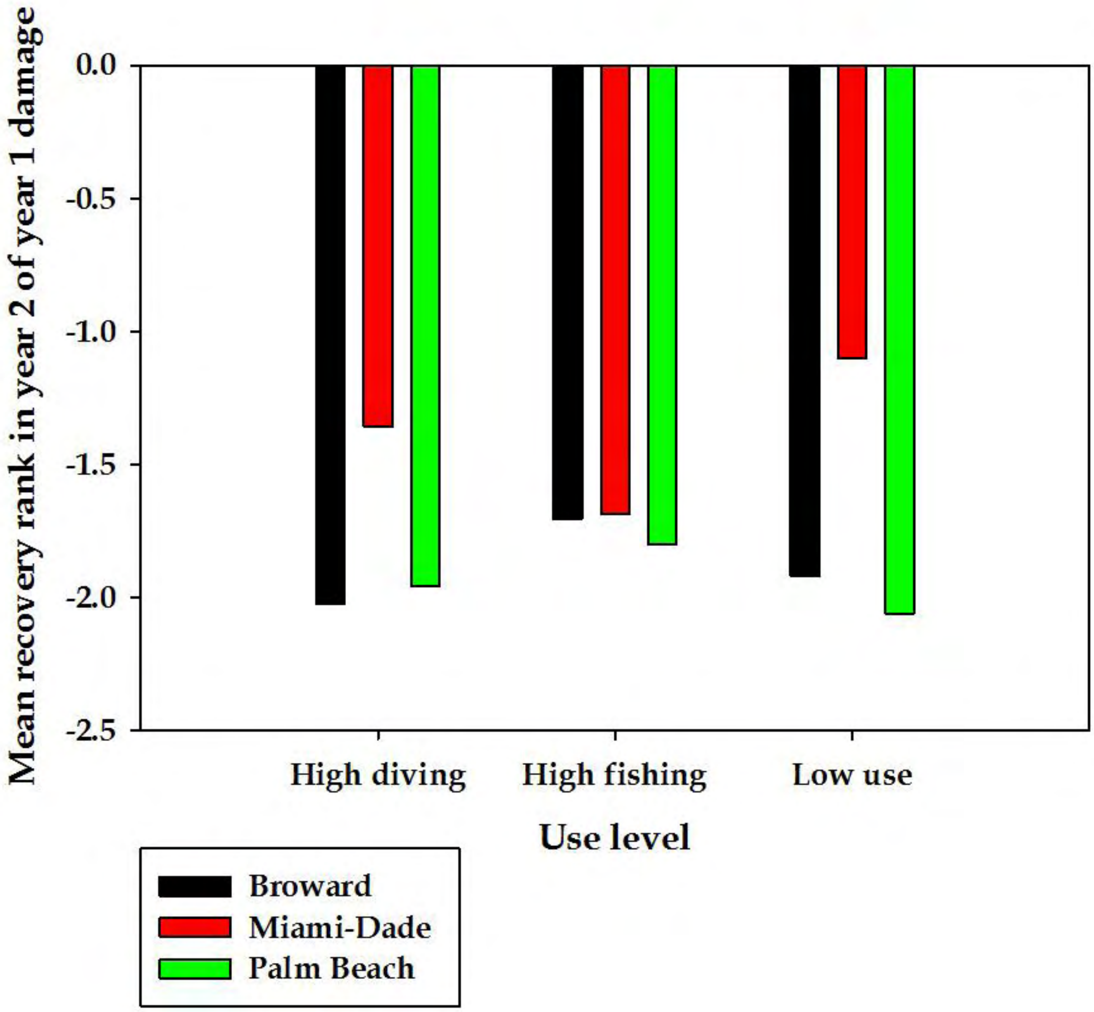


Figure 16. Mean recovery rank for damaged organisms in year 2 that were first observed in year 1, by county and use level.

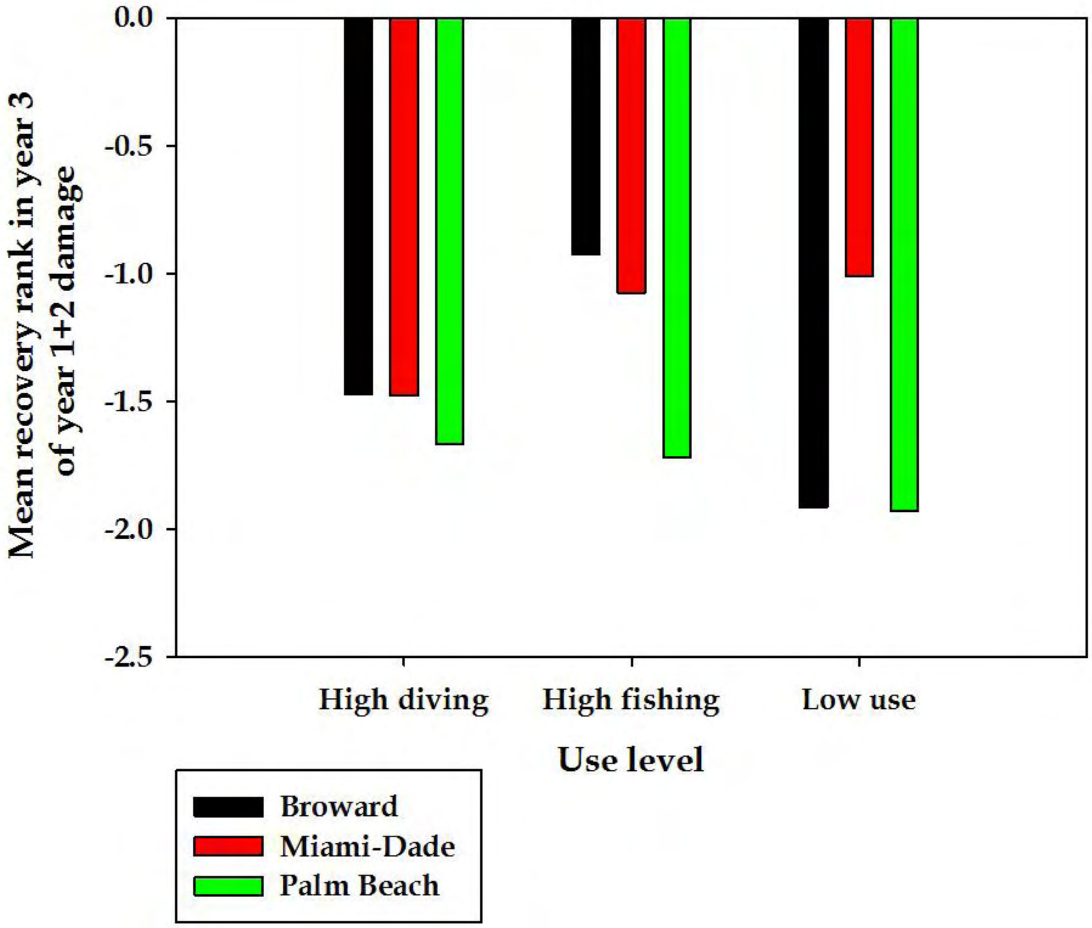


Figure 17. Mean recovery rank in year 3 of damaged organisms first observed in years 1 and 2, by county and use level.

4.3.2 Recovery of "new" damage versus damage of unknown age

There was no difference between use levels (P = 0.3725), counties (P = 0.6459), or any model terms between the mean recovery rank of damaged organisms first observed in year 1 (all damage to that date) and assessed in year 2, and those first observed in year 2 ("new" – damaged since year 1) and assessed in year 3 (Table 52, 53) (Fig. 16, 18). However, damaged organisms first observed in year 1 had a significantly higher (less negative) mean recovery rank than those first observed in year 2 (P = 0.0060) (Table 52, 53) (Fig. 18). Again, the mean recovery rank of all use level, county, and year combinations was negative, indicating organisms tended to decline following damage (Fig. 16, 18).

Table 52. Repeated-measures linear model of the effect of year first observed (year), use level, and county on the recovery rank of damaged organisms observed in year 1 and assessed in year 2, and damaged organisms observed in year 2 and assessed in year 3. Year denotes year damage was first observed.

Effect	Num df	Den df	F Value	Pr > F
County	2	25.7	0.44	0.6459
Use level	2	25.8	1.03	0.3725
County*Use level	4	19.4	0.68	0.6140
Year	1	42.5	8.36	0.0060‡
County*Year	2	30.5	1.11	0.3426
Use level*Year	2	32.9	0.71	0.5005

‡Denotes a significant result at $\alpha = 0.05$.

Table 53. Least squares means of recovery rank of damaged organisms observed in year 1 and assessed in year 2 and damaged organisms observed in year 2 and assessed in year 3, by year first observed (year), use level, and county.

Effect	County	Use level	Year	Estimate	Standard Error	df	t Value	Pr > |t|
County	Broward			-2.0426	0.2915	53	-7.01	<0.0001
County	Miami-Dade			-1.9388	0.3063	53	-6.33	<0.0001
County	Palm Beach			-2.1899	0.3131	53	-6.99	<0.0001
Use level		HD		-2.2217	0.3025	53	-7.34	<0.0001
Use level		HF		-1.8927	0.2819	53	-6.71	<0.0001
Use level		L		-2.0570	0.3236	53	-6.36	<0.0001
County*Use level	Broward	HD		-2.2357	0.3294	31.8	-6.79	<0.0001
County*Use level	Broward	HF		-1.6977	0.3788	20.6	-4.48	0.0002
County*Use level	Broward	L		-2.1945	0.3941	17.6	-5.57	<0.0001
County*Use level	Miami-Dade	HD		-2.1003	0.4659	14.2	-4.51	0.0005
County*Use level	Miami-Dade	HF		-2.0148	0.3095	50.2	-6.51	<0.0001
County*Use level	Miami-Dade	L		-1.7014	0.3723	36.2	-4.57	<.0001
County*Use level	Palm Beach	HD		-2.3290	0.3632	19.8	-6.41	<.0001
County*Use level	Palm Beach	HF		-1.9656	0.3338	26.1	-5.89	<.0001
County*Use level	Palm Beach	L		-2.2750	0.5109	7.39	-4.45	0.0026
Year			1	-1.7405	0.2723	53	-6.39	<0.0001
Year			2	-2.3737	0.3018	53	-7.87	<0.0001

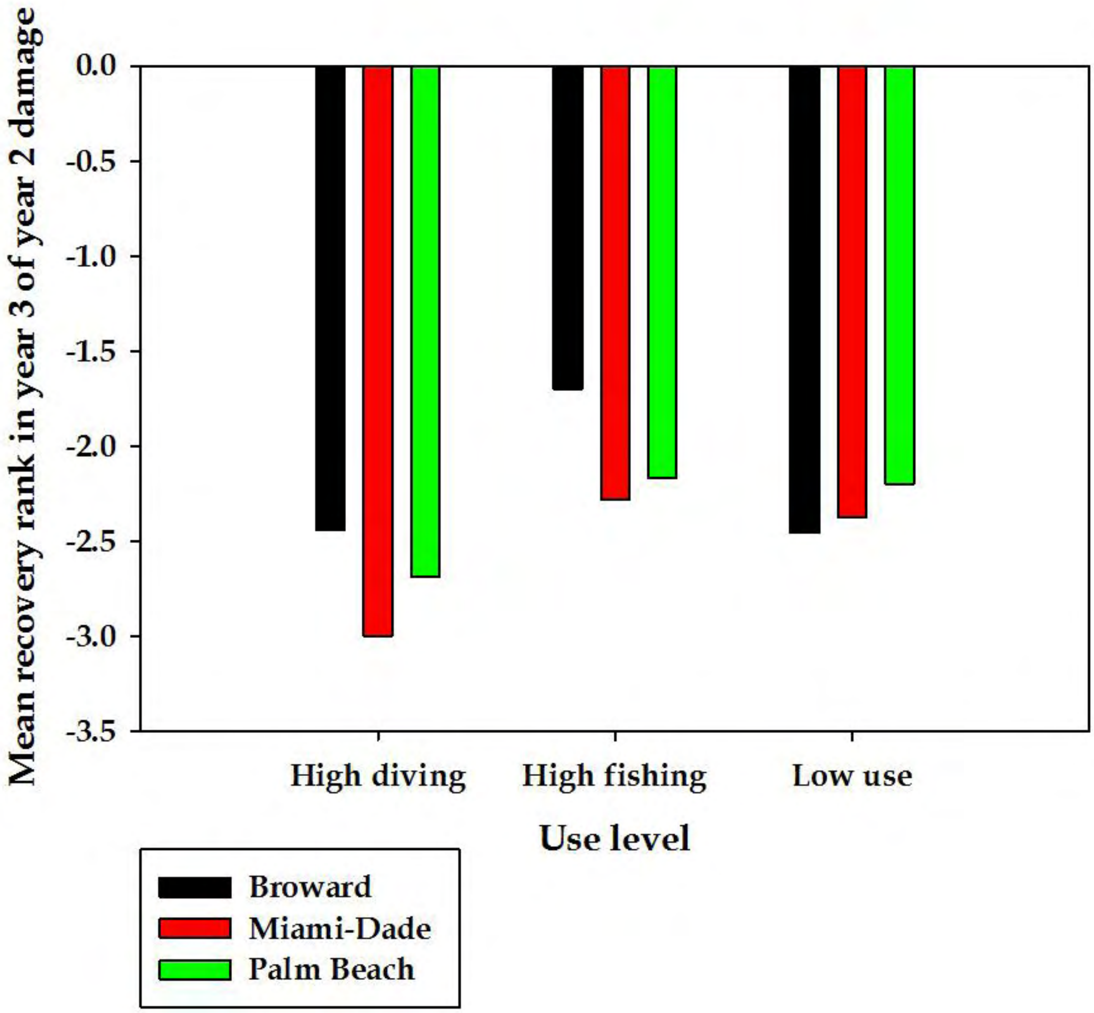


Figure 18. Mean recovery rank for damaged organisms in year 3 that were first observed in year 2, by county and use level.

4.4 Marine debris

There were no differences between the abundance of debris between use levels or any of the interactions, but there were differences between counties and years (Table 54, 55). Tukey's multiple comparisons analysis revealed that Palm Beach County had a significantly higher abundance of debris than either Broward (P = 0.0023) or Miami-Dade counties (P = 0.0006) (Table 56) (Fig. 19, 20). This analysis also revealed that the abundance of debris initially observed in year 1 was significantly greater than the abundance initially observed in either year 2 (P < 0.0001) or 3 (P = 0.0026), but the abundances initially observed in years 2 and 3 were similar (P = 0.9769).

Table 54. Results of a repeated-measures linear mixed model on the effects of survey year, use level, and county on the abundance of marine debris.

Effect	Num df	Den df	F Value	Pr > F
Year	2	32.3	13.68	<0.0001‡
County	2	24.5	11.40	0.0003‡
Year*County	4	34.9	0.64	0.6346
Use level	2	24.5	0.14	0.8672
Year*Use level	4	34.9	0.57	0.6831
County*Use level	4	24.5	0.63	0.6452
Year*County*Use level	8	36.3	1.19	0.3341

‡Denotes a significant result at $\alpha = 0.05$.

Table 55. Least squares means of debris abundance by survey year and county.

Year	County	Estimate	Standard Error	df	t Value	Pr > |t|
1		1.6870	0.1545	21.9	10.92	<0.0001
2		0.8113	0.1365	22.0	5.94	<0.0001
3		0.8501	0.1853	23.1	4.59	0.0001
	Broward	0.7524	0.2201	24.5	3.42	0.0022
	Miami-Dade	0.7436	0.1765	24.5	4.21	0.0003
	Palm Beach	1.8523	0.1860	24.5	9.96	<0.0001

Table 56. Differences in least squares means (adjusted for Tukey-Kramer multiple comparisons) among years and counties.

Year	County	Year	County	Estimate	Std Error	df	t Value	Pr > |t|	Adjust	Adj P
1		2		0.8757	0.1676	32.6	5.22	<0.0001	Tukey-Kramer	<0.0001‡
1		3		0.8369	0.2293	42.5	3.65	0.0007	Tukey-Kramer	0.0026‡
2		3		-0.03886	0.1887	28.3	-0.21	0.8383	Tukey-Kramer	0.9769
	Broward		Miami-Dade	0.008777	0.2821	24.5	0.03	0.9754	Tukey-Kramer	0.9995
	Broward		Palm Beach	-1.0999	0.2882	24.5	-3.82	0.0008	Tukey-Kramer	0.0023‡
	Miami-Dade		Palm Beach	-1.1087	0.2564	24.5	-4.32	0.0002	Tukey-Kramer	0.0006‡

‡Denotes a significant result at $\alpha = 0.05$.

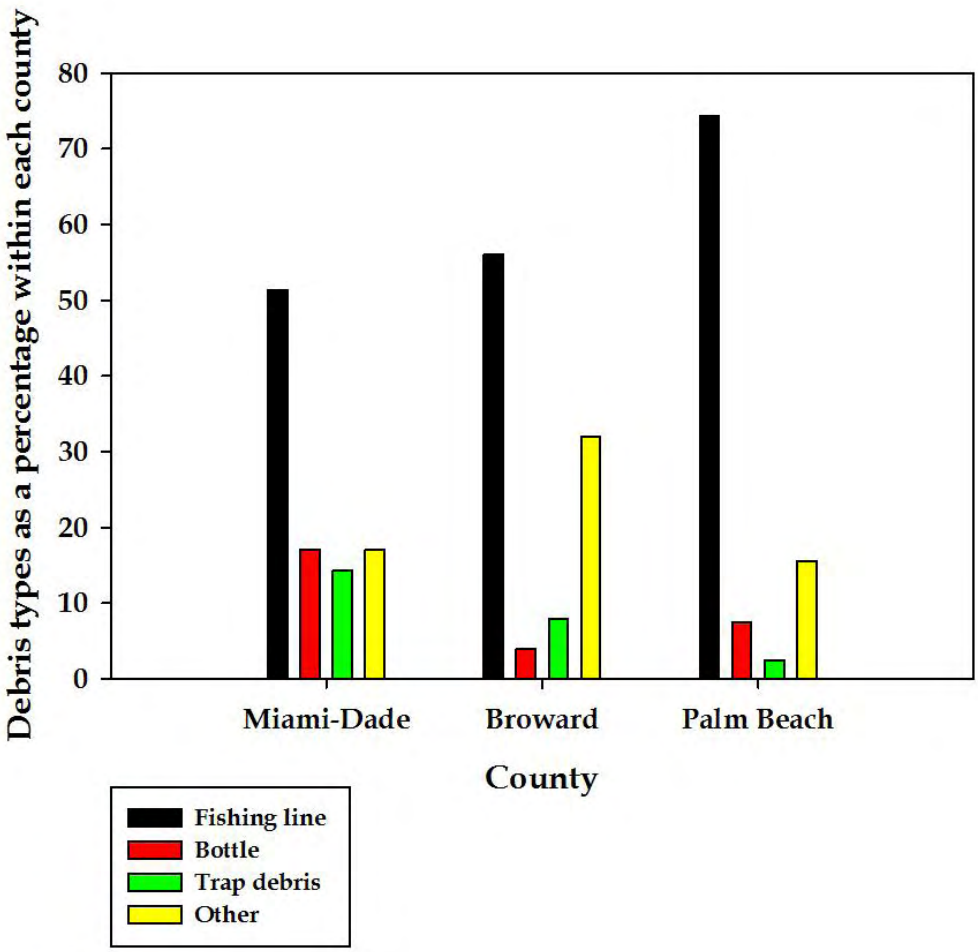


Figure 19. Percentage of marine debris in each county as a percentage of all the marine debris in the county. "Other" debris includes anything that did not fit the other categories including plastic cups, pieces of glass, plastic bags, etc. N = 220 unique pieces of marine debris.

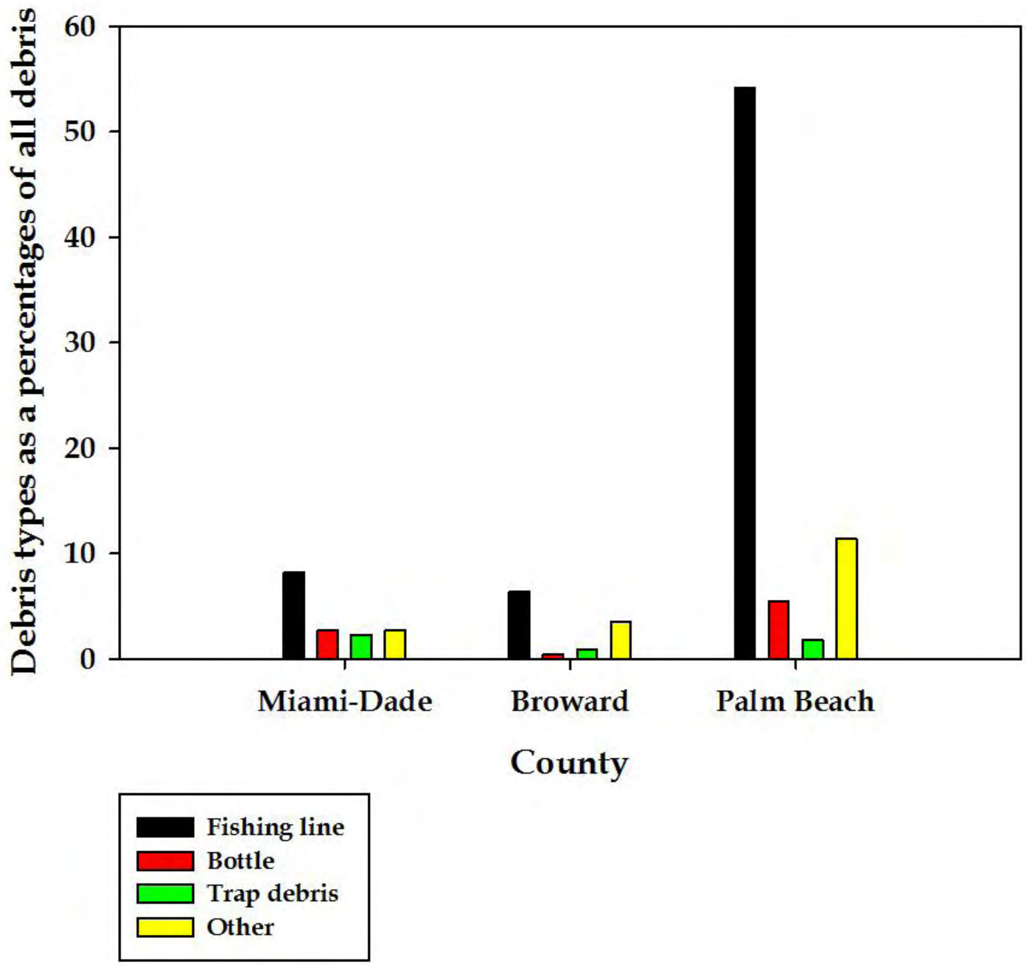


Figure 20. Percentage of marine debris in each county as a percentage of all the marine debris observed in the tri-county study area. "Other" debris includes anything that did not fit the other categories including plastic cups, pieces of glass, plastic bags, etc. N = 220 unique pieces of marine debris.

4.5 Bleaching and disease

Although these characteristics where recorded for the organisms observed, they were very infrequent. Bleaching is typically associated with late summer and early fall when water temperatures are at their peak and many sites were not surveyed during this time. Disease was similarly infrequent with only dark spot syndrome occasionally noted for *Siderastrea siderea* colonies. The study was not designed to focus on these characteristics, nor did we survey all of the sites during the same time of year. As a consequence we were not confident in any conclusions drawn from these observations.

4.6 Environmental correlations

The environmental variables that were significantly correlated with damage were dead coral cover (all three organism damage categories) and rugosity (hard coral and barrel sponge damage only) (Table 57).

Table 57. Correlations between depth, rugosity, and benthic coverage environmental variables and the three damage categories. Calcareous and felshy algae were combined into algae, and rubble and sand were combined into loose substrate to simplify the analysis.

Variable (%)	by Variable	Spearman ρ	Prob> |ρ|
Hard coral and barrel sponges damaged	Mean depth	-0.142	0.4157
Hard coral and barrel sponges damaged	Mean rugosity	0.3754	0.0263‡
Hard coral and barrel sponges damaged	Algal cover	-0.0899	0.602
Hard coral and barrel sponges damaged	Dead coral cover	0.4718	0.0037‡
Hard coral and barrel sponges damaged	Live coral cover	-0.0682	0.6926
Hard coral and barrel sponges damaged	Loose substrate	0.0186	0.9141
Hard coral and barrel sponges damaged	Pavement substrate	0.031	0.8574
Hard coral and barrel sponges damaged	Sponge cover	-0.1642	0.3385
Gorgonians damaged	Mean depth	-0.0591	0.736
Gorgonians damaged	Mean rugosity	0.1092	0.5324
Gorgonians damaged	Algal cover	-0.161	0.3483
Gorgonians damaged	Dead coral cover	0.4133	0.0122‡
Gorgonians damaged	Live coral cover	-0.1791	0.2958
Gorgonians damaged	Loose substrate	0.1353	0.4313
Gorgonians damaged	Pavement substrate	0.2049	0.2306
Gorgonians damaged	Sponge cover	0.042	0.8079
All organisms damaged	Mean depth	-0.0798	0.6487
All organisms damaged	Mean rugosity	0.2467	0.1531
All organisms damaged	Algal cover	-0.1654	0.335
All organisms damaged	Dead coral cover	0.4752	0.0034‡
All organisms damaged	Live coral cover	-0.1827	0.2862
All organisms damaged	Loose substrate	0.0855	0.6201
All organisms damaged	Pavement substrate	0.1516	0.3776
All organisms damaged	Sponge cover	-0.1069	0.5351

‡Denotes a significant result at $\alpha = 0.05$.

5.0 Discussion

This study sought to determine if coral reef use type, level of use, and county predicted the amount of damage a reef receives and if the rate of new damage exceeded or was exceeded by the recovery rate. The former would predict that the use level was unsutainable, while the latter would predict the opposite. Marine debris was also investigated in this framework to determine if there were differences between these user groups or counties in the abundance of debris encountered on the coral reefs.

5.1 Instantaneous damage

From this study of coral reef impacts associated with activity and use level, Miami-Dade County had significantly more hard coral and barrel sponge damage, more gorgonian damage, and more total damage than either Broward or Palm Beach counties, even after accounting for differences in the relative abundance of each organism type on the sites. The majority of these differences between counties appears to have derived from high fishing and low use sites. The damage on high diving sites was similar between the counties except when considering only hard corals and barrel sponges, where Palm Beach County was visibly lower.

Boat anchoring can be a major source of damage to coral reefs adjacent to heavily populated areas, resulting in dislodged or broken hard corals, gorgonians, and sponges. Many sources of reef degradation such as ocean warming, eutrophication, ocean acidification, and over-fishing are controversial and even if addressed will take years, decades, or longer to reverse. However, damage to coral reefs as a result of anchoring is immediate but manageable. With an appropriate management program, including education and awareness, this source of damage can be greatly reduced or eliminated.

Southeast Florida has a huge human population, and not surprisingly, the coral reefs adjacent to this area receive considerable use pressure - particularly Miami-Dade County. Miami-Dade County reefs receive nearly twice the proportion of anchoring than either Broward or Palm Beach County (Behringer and Swett 2011) and this intensity of anchoring in Miami-Dade may correlate with greater reef damage. The coral reefs used in Broward County are part of a continuous tract with Miami-Dade County reefs, so it is reasonable to assume they *should* receive similar anchoring pressure. However, at the time of a recent vessel use study (Behringer and Swett 2011), Broward was the only county to have an extensive mooring buoy program (122 buoys). Assuming boaters would anchor if a mooring buoy were not available, the difference in anchoring between Miami-Dade and Broward might be explained by the use of mooring buoys in Broward. The difference between Miami-Dade and Palm Beach is more likely a function of deeper reefs with strong and unpredictable currents in Palm Beach that make anchoring impractical for many users, particularly divers.

5.2 Yearly damage

As expected, the percentage of damaged organisms first observed in year 1 included all observable damage to that date and thus exceeded that of years 2 and 3 for hard corals and barrel sponges, and all damage combined. While the percentage of damaged hard corals and barrel sponges continually decreased each year in each county, this was not true for gorgonians. Years 1 and 3 were not different for the percentage of damaged gorgonians, indicating that these organisms are more consistently impacted. Gorgonians are potentially more susceptible to dislodgement due to their small attachment point and the area they extend into the water column relative to the size of this point.

The singular effect of county on percentage damage was seen in the coral and barrel sponge damage with Miami-Dade county having greater damage than Palm Beach county, regardless of year. County was also a factor in the interaction effect between county and year for gorgonian and all damage combined. Similar to the instantaneous analysis for both gorgonians and all damage combined in year 1, Miami-Dade exhibited the greatest percentage of damage. However, the percentage of damaged gorgonians in Broward County increased from year 1 to year 2 while it decreased in Miami-Dade and Palm Beach counties. This resulted in Broward County having a significantly higher percent gorgonian damage in year 2, and pushed the percentage of all damaged organisms combined in Broward to a significantly higher level than Miami-Dade and Palm Beach counties in year 2. Were it not for this inexplicable increase in gorgonian damage in Broward in year 2, there would have been no county*year interaction beyond year 1.

The effect of use level was only significant for gorgonian damage. High diving and low use sites had greater gorgonian damage than high fishing sites. The differences observed in use were not highly significant ($P = 0.0500$ and 0.0418, respectively) and this pattern again points to the high level of damage in southeast Florida, regardless of county or use level.

5.3 Recovery

Use level had no effect on the mean recovery rank and this is not surprising considering that use level is unlikely to affect recovery unless organisms are damaged repeatedly – an action not specifically observed. However, there was a difference between counties. Palm Beach County may have had a lower mean recovery rank than Miami-Dade County when all damage was considered (section 4.3.1) because the damage in Miami-Dade County has accumulated over time (see section 5.1- significantly more damage observed in year 1) and much of it may have stabilized. Indeed, damaged organisms appear to degrade more rapidly within the year following damage and then appear to stabilize. This is also evident in the differences in mean recovery rank between years. The mean recovery rank for damaged organisms first observed in year 2 and assessed in year 3 was much lower (more negative) than the mean rank of damaged organisms first observed in year 1 and assessed in year 2. Moreover, when the mean recovery rank was combined (years 1+2) for the year 3 assessment, it raised the mean recovery rank so high that it became significantly higher (more positive) than the mean recovery rank of year 1 damage observed in year 2. However, it is important to note that the mean recovery rank of damaged organisms was negative overall, regardless of the category (use level, county, or year), indicating that on average they declined over time.

5.4 Marine debris

We were unable to track the movement and fate of debris because it always either remained in the spot on the transect where it was originally observed (often encrusted to the substrate) or was missing from the transect. Dive time limitations did not permit us to search widely for the missing debris. Therefore, we considered only the abundance of debris through time. There were no differences between use levels, but Palm Beach County had significantly more debris than either Miami-Dade or Broward counties. In all counties fishing line was the most abundant type of marine debris, accounting for > 50% of the within county debris. Fishing line also accounted for the difference in debris between Palm Beach and the other counties with > 50% of the *total debris in the tri-county region* being fishing line in Palm Beach County. The high percentage (15%) of debris potentially from lobster traps (trap weights and polypropylene line) in Miami-Dade County is also of interest as it supports the possibility that some of the damage that has occurred in Miami-Dade County is the result of lobster trap fishing.

5.5 Environmental correlates

The significant correlation between dead coral cover and the percentage of damage in all three organism categories is unlikely to have affected the amount of damage observed but rather supports the possibility that heavily impacted sites have been cronically impacted, resulting in a high abundance of dead organims. Rugosity is logically associated with the abundance of rugosity-generating organisms such as hard corals and barrel sponges. However, bias that might have been associated with this was accounted for in the analysis by using the percentage of damaged organims relative to their total abundance, not the absolute abundance.

5.6 Study limitations

It is important to note that although we call the organims observed "damaged", there is no way to conclusively determine that it was indeed such. Care was taken to train all divers and image technicians on what to consider damage and care was taken to eliminate from consideration any organims that appeared to be injured by predation, disease, or other natural means. However, all site treatments and counties were treated similarly so any differences between them could be considered actual differences resulting from those factors.

The lack of difference or consistency in difference between the use level treatments could have arisen from several sources, but is most likely due the extensive use of all of the reefs in southeast Florida. Many of the low use sites had signs of activity, particulary commercial lobster fishing (e.g., trap debris and line). It may be that low use sites are sites so degraded that they are no longer attractive to divers and fishermen, so appeared from aerial surveys to be "unused". The lack of consistent differences between diving and fishing sites could also have arisen from multi-purpose use of most sites and because both uses often require boat anchoring. The limited number of aerial surveys available from which to select sites may have missed multiple use patterns.

5.7 Conclusions

Although the use level design of the study did not identify significant and consistent differences between them, this is in itself important. It shows that all reefs in Miami-Dade, Broward, and Palm Beach counties receive intense pressure and probably more than they can sustain. There are no marine protected areas that could serve as sanctuary for any organism. The significant difference in damage between Miami-Dade and Broward counties in year 1 highlights the potential effectiveness of an extensive mooring bouy program at protecting organisms from the breakage and dislodgement likely to occur from unabated anchoring. Although this finding is correlative and does not show definitive cause and effect, it is compelling and warrants further study.

6.0 Literature cited

Behringer DC and RA Swett. 2011. Determining vessel use patterns in the southeast Florida region. Miami Beach, FL. Pp 88.

Florida Fish and Wildlife Conservation Commission. 2005. Florida's Wildlife Legacy Initiative. Florida's Comprehensive Wildlife Conservation Strategy. Tallahassee, Florida, USA.

Saphier, A.D., and T.C. Hoffman. 2005. Forecasting models to quantify three anthropogenic stresses on coral reefs from marine recreation: anchor damage, diver contact and copper emission from antifouling paint. Marine Pollution Bulletin 51:590–598.

Smith, L.D., and T.P.Hughes. 1999. An experimental assessment of survival, re-attachment and fecundity of coral fragments. Journal of Experimental Marine Biology and Ecology 235:147–164.

United States Coast Guard. 2009. Recreational Boating Statistics 2009. COMDTPUB P16754.23.

Wulff, J.L. 1995. Effects of a hurricane on survival and orientation of large erect coral-reef sponges. Coral Reefs 14:55-61.