Determining Vessel Use Patterns in the Southeast Florida Region

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

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

Determining Vessel Use Patterns in the Southeast Florida Region

Final Report

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Executive Summary

Globally, coral reefs are under intense pressure from human activities (Lirman and Miller 2003, Saphier and Hoffman 2005, Markey et al 2007) and environmental stressors (Bruno et al 2007, Edmunds and Elahi 2007). In southeast Florida, the pressure from human use is particularly acute, owing to exceptionally large human populations in coastal counties and the close proximity of the reefs to shore. The 566,560 ha of coral reefs in Florida represent the only barrier reef system in the continental U.S and this exceptional natural resource draws high numbers of boaters. Florida recognized the importance of coral reefs and listed them as a "priority habitat" and designated their overall habitat threat category as "very high" (FWC 2005).

To abate stress to coral reefs, a priority action of the state is the "development of a vessel anchoring management plan" (FWC 2005). Such a plan must be based on an understanding of vessel use patterns and associated activities in order to apply effective, place-based management. A particular need is a spatially explicit assessment of boating patterns and their association with benthic features. The resource managers and stakeholders of the Southeast Florida Coral Reef Initiative recognized the need for this information and, therefore, prioritized this project.

This project used aerial surveys to determine use intensity, anchoring pressure, and predominant boating activities off Miami-Dade, Broward, Palm Beach, and Martin counties. Results showed that small vessels (85%) dominated those observed, and most of those were recreational (90%). Nearly all vessels observed (95%), regardless of their class or size, were either fishing or diving/snorkeling. A third (32%) of all vessels were anchored, 90% of these were < 10 meters (m) in estimated length and significantly more recreational vessels were anchored compared to commercial. Thus, management targeting this class and size of vessel would be likely to provide the most return for effort.

There were more recreational vessels on weekends/holidays than on weekdays, and more large vessels (> 20 m) on weekdays. Fishing dominated the activities on weekdays over diving/snorkeling. Use level also had an effect on the frequency of anchoring with more anchoring on weekends/holidays. This is due to more diving/snorkeling and more recreational vessels on weekends relative to weekdays.

Lobster mini-season season had a particularly dramatic effect on use patterns. Indeed, spatial pattern analysis revealed that the distribution of vessels observed during the mini-season flight was significantly different from that of other flights. In general, vessels observed during the mini-season were closer to shore than were vessels observed during the other nine flights. Further analysis

showed that significant clustering of non-mini season vessels occurred in the outer portions of the study area and that these clusters were associated with specific habitat types, in particular reefs. Specific associations of vessel clusters and benthic habitat were mapped within a Geographic Information System (GIS).

The results of this project give a clearer understanding of the levels and types of pressure southeast Florida coral reefs experience and will allow resource managers such as Florida Department of Environmental Protection (FDEP), Florida Fish and Wildlife Conservation Commission (FWC), National Oceanic and Atmospheric Administration (NOAA), and county governments to more effectively target conservation efforts on areas receiving the most intensive use. Furthermore, the spatial analysis provides information with which to focus future investigations. Given the large spatial extent of the area, the information provided in this report will allow the creation of protocols to sample, for example, areas of low to high use. Correspondingly, plots to monitor habitat could be established that are associated with the areas selected to monitor and map use patterns. The additional information generated from such efforts would greatly enhance the ability to develop appropriate management actions.

1.0 Introduction

Globally, coral reefs are under intense pressure from human activities and environmental stressors. In southeast Florida (Fig. 1) the pressure from human use is particularly acute, owing to the exceptionally large human populations in coastal Miami-Dade, Broward, Palm Beach, and Martin counties (Fig. 2); and the close proximity of the reefs to shore. In addition to threats from climate change (Bruno et al. 2007), disease (Edmunds and Elahi 2007), pollution (Markey et al. 2007), and vessel groundings (Lirman and Miller 2003), there are those that arise from boating activities including anchor damage (Saphier and Hoffman 2005), fishing gear damage, and recreational impacts (fishing and diving) (Barker and Roberts 2004). The 566,560 ha of coral reefs in Florida represent the only barrier reef system in the continental U.S. This exceptional natural resource draws high numbers of boaters. Based on an analysis of Coast Guard boating statistics between 2000 – 2009, 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 2010) (Fig. 3).

The FWC recognized 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 Strategy (FWLS) (FWC 2005). Furthermore, in 2008 the National Marine Fisheries Service designated part of southeast Florida as "critical habitat" for corals of the genus Acropora, listed by the Endangered Species Act as "endangered." One of the four actions identified for abating stress to coral reefs in the FWLS is "development of a vessel anchoring management plan and use of mooring buoys." Fulfillment of this action requires knowledge of vessel use patterns and associated activities.

Federal (NOAA), State (FDEP), and local (county) resource managers and other stakeholders have recognized the threat that boating pressure applies to reefs. The team of interagency marine resource professionals, scientists and other stakeholders who developed the Southeast Florida Coral Reef Initiative (SEFCRI) prioritized a project to evaluate the vessel use and activity patterns within the southeast Florida region (Miami-Dade, Broward, Palm Beach, and Martin counties). This project used aerial surveys to determine use intensity, anchoring pressure, and predominant activities over the entire region and associate use level with specific areas of the reef tract. The results of this project give a clearer understanding of the levels and types of pressure southeast Florida coral reefs experience and will allow resource managers such as FDEP, FWC, NOAA, and county governments to more effectively target conservation efforts on areas receiving the most intensive use.

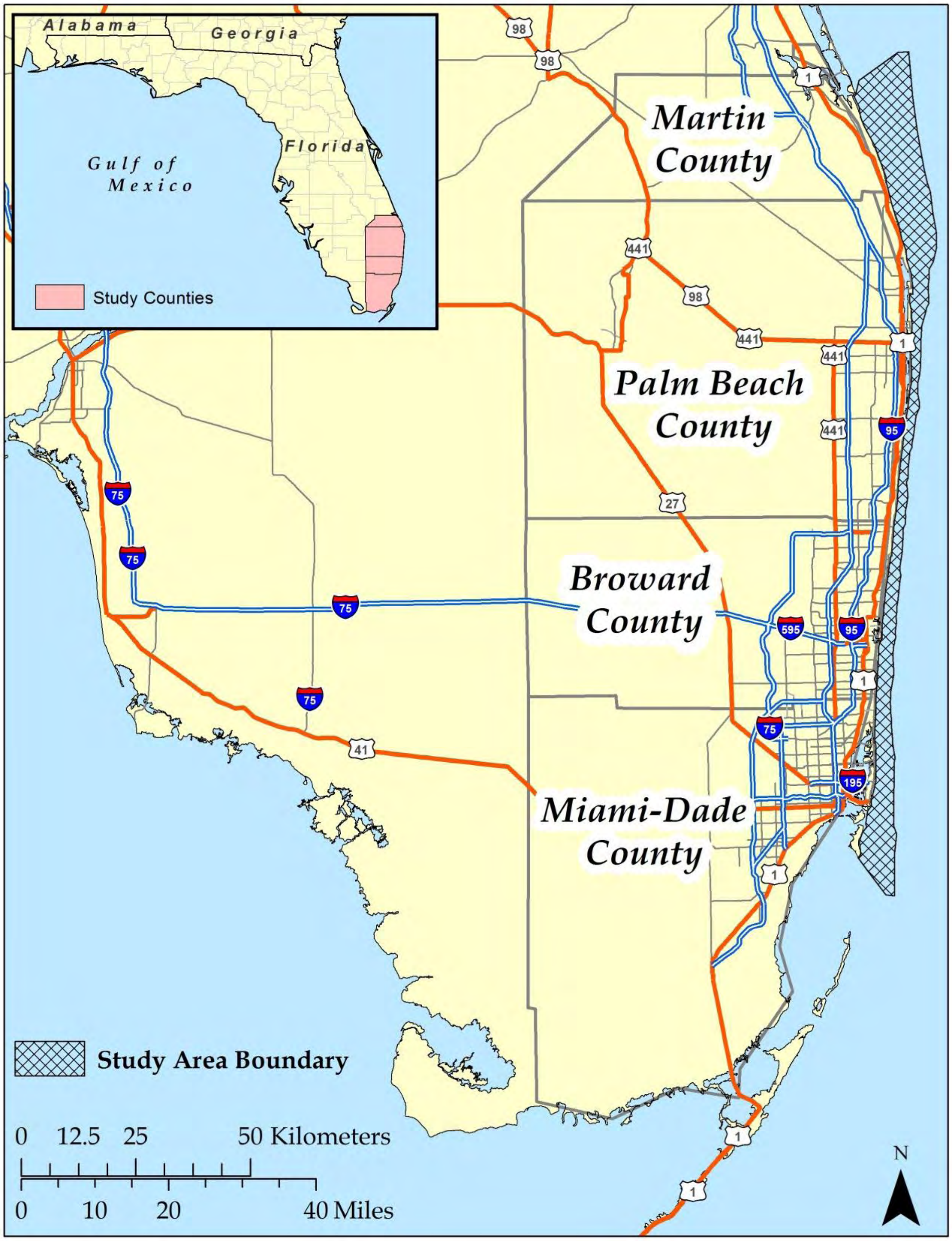

Figure 1. Southeast Florida region (Miami-Dade, Broward, Palm Beach, and Martin counties) and study area boundary.

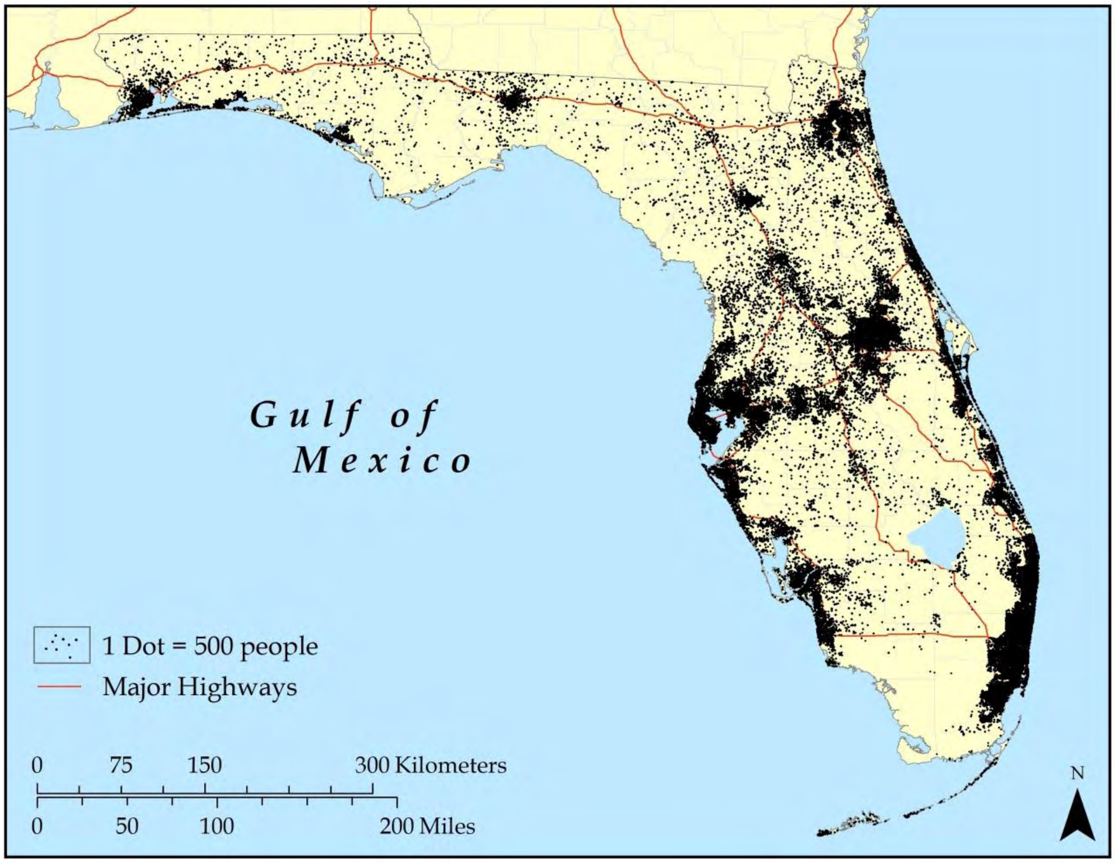

Figure 2. Relative distribution of Florida's 2009 population, by census tract.

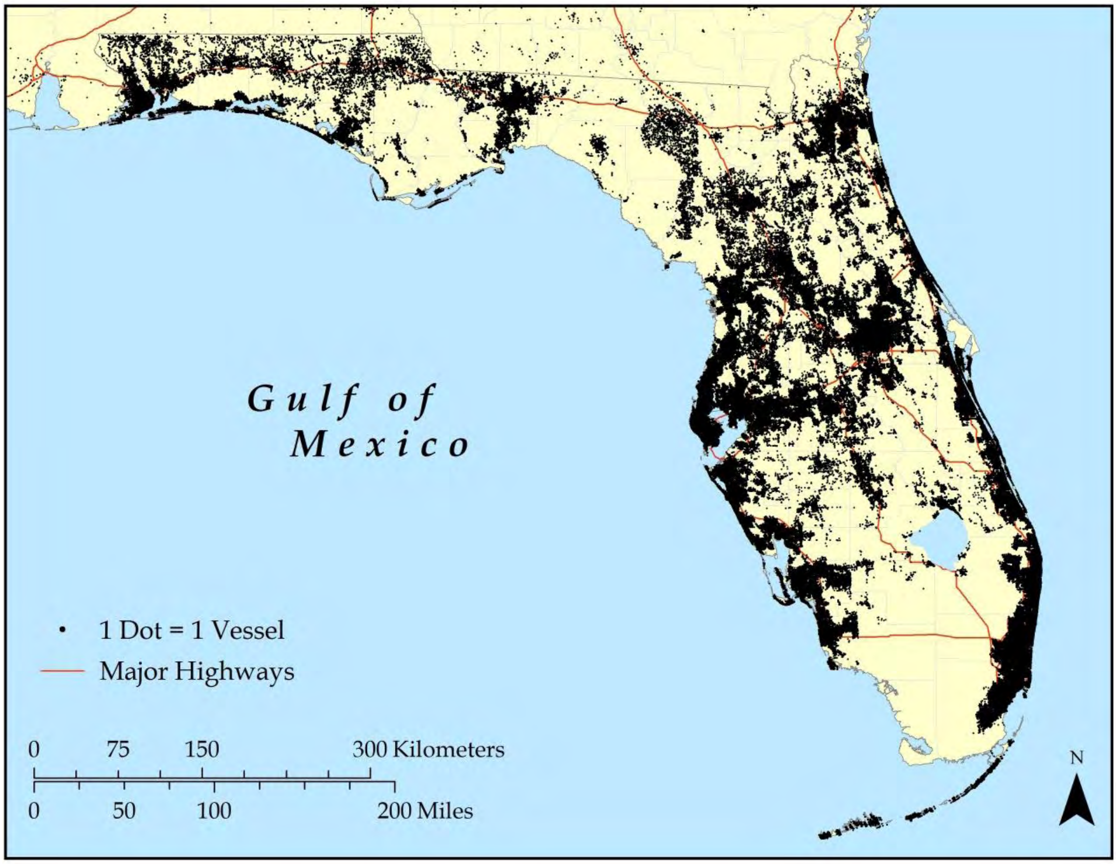

Figure 3. Distribution of vessels registered in Florida, by owner address.

2.0 Goals and Objectives

2.1 Goals

The goal of this study was to provide an initial assessment of vessel use patterns on the natural reefs of the southeast Florida region (Miami-Dade, Broward, Palm Beach, and Martin counties). In addition, we sought to develop methods that would form the basis for a standardized, repeatable approach to monitoring and characterizing the coral reef usage patterns by recreational and commercial vessels. Ultimately, the patterns described and methods developed were meant to form a tool for managers to use in conserving and protecting the coral reefs of southeast Florida.

2.2 Objectives

a) Describe vessel use patterns within the southeast Florida region, extending from the Fowey Rocks Lighthouse on the northern border of Biscayne National Park to the St. Lucie Inlet.

b) Describe associations between descriptive vessel categories and activities.

3.0 Methods

Previous fixed wing aerial survey studies have documented vessel use in south Florida (McClellan 1996, Ault et al. 2008a, Ault et al. 2008b). Those studies focused on different areas (e.g., Ault 2008a – Biscayne National Park, and 2008b – Everglades National Park) and had different purposes than we had for this study. The primary objective of our study was to associate use patterns with spatially specific reef segments (map units). Therefore, the methods by McClellan and Ault were not appropriate for this study because they do not supply the resolution that we sought. Furthermore, the focus of Ault et al. (2008a, b) was to establish a repeatable method for using boat ramp trailers as a proxy for use, which is not a focus of this study.

Below we describe the methods we developed for the collection of data describing spatial use patterns in southeast Florida waters by recreational and commercial vessels.

3.1 Vessel assessment

Laser Airborne Depth Sounder (LADS) and Compact Hydrographic Airborne Rapid Total Survey (CHARTS) data, available nautical charts and a benthic geomorphic classification were used to delineate coral reef segments within the southeast Florida reef region. A description of the reef segmentation methodology is included below. These data and associated Land Boundary Information Systems (LABINS) orthophotographs formed the basemap for the organization and presentation of all collected and compiled data. Flight lines and waypoints were derived from the base map. Vessel-related data were collected through a technique that combined aerial survey, a global positioning system (GPS), laser range finding, and photography.

3.2 Periods of use

Vessel information was collected within three specified levels of use as determined by the Fishing, Diving, and Other Uses (FDOU) Project 33A Team: low-use, medium-use, and high-use. Three data collection (helicopter) flights occurred during each use level. For each use level one flight occurred in the spring, one in the summer, and one in the fall. Although not statistically testable due to a lack of replication within each season, this design was selected by the FDOU Project 33A Team to determine if a seasonal component in use patterns exists. An additional flight was added for the Florida spiny lobster "mini-season," a yearly two-day event focused on the recreational harvest of lobsters. The mini-season occurs on the last consecutive Wednesday and Thursday in July and, typically, is characterized by heavy diving activity. The specific flight days for each use level and for the mini-season were as follows:

a) Low-use (weekdays)
    a. Tuesday, 04/29/08
    b. Wednesday, 07/02/08
    c. Thursday, 11/19/09
b) Medium-use (weekends)
    a. Sunday, 05/04/08
    b. Saturday, 07/12/08
    c. Saturday, 09/19/09 & Saturday, 10/03/09[1]
c) High-use (holidays)
    a. Saturday, 05/24/08 (Memorial Day weekend)
    b. Sunday, 07/05/08 (4^{th} of July weekend)
    c. Friday, 09/05/09 (Labor Day weekend)
    d. Wednesday, 07/30/08 (lobster "mini-season")

3.3 Data collection standards

Data collection commenced in the morning between 8 am and 9 am to ensure that the entire study area could be completed in a single day and during daylight hours. The start and end times of each survey were recorded.

Start and end points were held constant due to the limited number of surveys. The coral reefs in Miami-Dade and Broward counties are the most extensive and accessible (shallow, near-shore, close inlet proximity), therefore, we elected to initiate all surveys at the Fowey Rocks Lighthouse and terminate them at the St. Lucie Inlet. The eastern boundary of the study area was delineated as the 35 m isobath by consensus of the FDOU 33A Team. The basis was their perception that anchoring would be very infrequent beyond this depth.

The entire southeast Florida region as delineated in the base map (Fig. 1) was surveyed during each data collection. An example of the flight path is shown in Appendix 8.1.

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[1] Inclement weather forced the abortion of the 9th flight on 9/19/09 before the entire study area had been surveyed; the area that remained was surveyed on 10/03/09.

[2] FGDC stands for Federal Geographic Data Committee. The FGDC develops data standards that

Data collection was limited to conditions deemed "adequate for boating" by the FDOU Project 33A Team. Surveys were only conducted if the NOAA marine forecast/conditions were as follows:

a) Wind: 10 – 15 knots or less
b) Precipitation: 50% or less
c) Air temperature: > 70° F (21° C)
d) Cloud cover: clear to partly cloudy

General weather conditions were noted at the start of each data collection event and any significant changes were recorded.

3.4 Vessel information

Vessel positions were recorded using a Trimble® Recon® field computer with a Trimble GSP Pathfinder XB receiver and a laser rangefinder. To estimate the accuracy of vessel positions, a test was conducted that involved taking multiple postions (602) of the hood of a car while on the ground and then while hovering in the helicopter. The test resulted in an estimated horizontal accuracy of 19 meters.

A picture of each vessel was taken and post-processing then associated each photo with its corresponding vessel for viewing in ArcGIS®, Google Earth™, or in a web browser. The process is explained in Appendix 8.2.

The following vessel categories and options (Table 1) were selected to encompass all feasible data that could be accurately gathered during the helicopter flight while minimizing time per vessel and maximizing investigator safety. For example, we did not attempt to enumerate the passengers on each vessel due to the likelihood that vessel cabins would obscure many. We also elected to separate some categories into multiple sub-categories to permit the greatest flexibility in the use of the data. For example, commercial headboats (defined here as a fishing boat that takes recreational fishermen out for a per person, or per head, fee) were recorded separately to allow for subsequent use pattern analysis of this particular class of vessels.

Commercial vessels were restricted to those that could be unequivocally determined as such (e.g., large commercial registration numbers or business advertisement). Vessels were categorized as "other" when their class, status, or activity could be determined but did not fit into any of the prescribed categories. Vessels were categorized as "unknown" when class or activity could not be determined.

Table 1. Survey data categories for vessels within the southeast Florida region.

Vessel Category	Definition	Options
Class	Type of vessel	1. Recreational 2. Commercial 3. Commercial (headboat) 4. Research 5. Other 6. Unknown
Size	Estimated length of vessel	1. < 10 m 2. 10 – 20 m 3. > 20 m
Status	What was the vessel doing?	1. Adrift 2. Anchored 3. Moored 4. Trolling 5. Other
Activity	What were the passengers doing?	1. Fishing and diving 2. Diving/ snorkeling 3. Fishing 4. Fishing (Trolling) 5. Other 6. Unknown

3.5 Geographic range

The south-north geographic range of the study area was delineated by the FDOU Project 33A Team as extending from the Fowey Rocks Lighthouse in the south to the St. Lucie Inlet in the north. The east-west geographic range of the study area was delineated by the FDOU Project 33A Team as extending from the 35 m isobath in the east to the coastline in the west.

3.6 Benthic Habitat Data

Existing GIS datasets that contained maps of coral, hard-bottom, and other habitats off Miami-Dade, Broward, Palm Beach, and Martin counties were used for this project. The habitat data were the results of mapping projects undertaken by Nova Southeastern University's Oceanographic Center in collaboration with NOAA, the FWRI (Fish and Wildlife Research Institute), and the FDEP Coral Reef Conservation Program (CRCP). The benthic habitat mapping efforts incorporated laser bathymetry, aerial photography, acoustic ground discrimination (AGD), video groundtruthing, limited subbottom profiling, and expert knowledge (Walker et al. 2008). The minimum mapping unit was one acre and total map accuracy was 93.0% off Miami-Dade County (Walker et al. 2008), 89.6% off Broward County (Walker et al., 2008), and 89.2% off Palm Beach County (Riegl et al. 2005). A draft version of habitat GIS data for Martin County habitat data was used for this project. The datasets were published in 11/2004 (Broward), 3/2007 (Palm Beach), and 6/2009 (Miami-Dade), respectively.

3.7 Metadata

FGDC[2]-compliant metadata were prepared for all primary data used to create deliverables for this study. The metadata accompanies the shapefile containing the vessel information.

3.8 GIS Compliance

The collection and production of geospatial data complied to the extent practicable, with Executive Order 12906, the National Spatial Data Infrastructure and FGDC standards.

3.9 Data analysis

The data from the aerial survey flights were analyzed categorically, spatially, and temporally. The categorical analysis was used to determine relationships between the data categories and overall use patterns based on the three use levels measured. The spatial analyses were based on the geographic and temporal distributions of the mapped vessels (i.e., where and when they were observed) and their characteristics. The analyses included an examination of general use (spatial) patterns and of use patterns associated with (a) specific habitat types, including reef segments (map units), (b) vessel activities, and (c) vessel status. The spatial and temporal analyses were conducted using ArcGIS® 10.0 spatial statistics tools for analyzing patterns, measuring geographic distributions, and mapping clusters; and SPSS[3] for parametric and non-parametric tests.

3.10 Statistical Analysis

To investigate general boater use patterns, irrespective of GPS location and reef segments, we employed a series of contingency table analyses to the categorical data. Contingency table analysis is appropriate for testing independence between

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[2] FGDC stands for Federal Geographic Data Committee. The FGDC develops data standards that facilitate the development, sharing, and use of geospatial data.

[3] SPSS is a computer program for statistical analysis sold by IBM.

categorical variables. Many of the categories were truncated to reduce unnecessary complexity. Those alterations are explained below. For contingency tables greater than 2x2, any significant results were followed up with pair-wise comparisons (Fisher's Exact test) to determine the source of the difference. Significance was determined at $\alpha = 0.05$.

We considered vessel class and size to be independent variables and the vessel activity and status to be dependent variables. We thus evaluated the relationship between each independent and each dependent variable separately. The vessel class data used in this analysis were restricted to "recreational" versus "commercial" vessels to ease interpretation. There were only 11 of 3,409 vessels that did not fall into one of these two categories (n = 1 research, n = 8 other, and n = 2 unknown). The vessel activity data were reduced to "fishing" versus "diving/snorkeling" by: a) combining "trolling" and "fishing" because trolling is a subcategory of fishing, b) not including "other" and "unknown" activities because of their very low occurrence, and c) not including "diving and fishing" because when comparing only fishing versus diving/snorkeling, diving and fishing fit both categories and so would not have affected the outcome of the analysis. The vessel status data were reduced to "anchored" versus "not anchored" by combining the categories adrift, trolling, other, and moored, as they are all "not anchored." This was done because determining anchoring intensity was a primary focus of this study and deemed the most likely cause of vessel damage to coral reefs.

4.0 Results

4.1 Vessel category frequency distributions

To graphically depict the general use patterns in the southeast Florida region, we generated frequency histograms for the various vessel categories. This was done for the entire southeast Florida region, by county, and finally by use level. In addition, we developed a series of frequency histograms specifically for anchored vessels to show the frequency of each vessel class, size, and activity for this status. The latter was done because anchor damage was a driving factor for this study, since it suspected as a likely cause of coral reef damage.

4.1.1 Vessel categories for the entire study region

Greater than 90% (n = 2,914) of all vessels observed (n = 3,406) were classified as recreational (Fig. 4). However, some commercial vessels may have been classified as recreational, inadvertently, if they lacked distinguishing commercial characteristics such as visible registration numbers, commercial fishing gear (e.g., lobster traps), or business advertisement. Included were commercial charter vessels that often bore no distinction from similar private vessels. In the latter case, the clients are recreational fishermen, but the vessel is commercial. The remaining categories were of negligible frequency. The “other” category included any vessel that did not fit the defined options but where the class could be identified (e.g., navy vessel).

Greater than 85% (n = 2,904) of all vessels were estimated to be < 10 m in length (Fig. 5). Less than 1% (n = 33) of vessels observed were > 20 m and most of these were commercial headboats, cargo ships, or tankers.

Greater than 32% (n = 1,120) of vessels observed were anchored (Fig. 6). A vessel was only considered anchored if the anchor line was clearly visible. The majority of the remaining vessels (67%, n = 2,286) were adrift (49%, n = 1,677), trolling (12%, n = 409), moored (to mooring buoys, navigational markers, or other fixed structures) (5.5%, n = 189), or underway (0.3%, n = 11). The “other” category included any vessel that did not fit the defined options but where the vessel status could be identified (e.g., towing another vessel).

After combining fishing and trolling, 59% of all vessels observed were fishing (n = 1,992) (Fig. 7). Diving or snorkeling comprised 36% (n = 1,220) and the remaining categories combined for 5%. The “other” category included any vessel that did not fit the defined options but where the vessel activity could be identified (e.g., sunbathing).

More vessels were observed during weekends (35%, n = 1,200) than weekdays (15%, n = 512), but the percentage observed during holidays (50%, n = 1,697) was nearly equivalent to weekdays and weekends combined (Fig. 8). There also were more vessels observed during the summer (43%, n = 1,470) than either the spring (29%, n = 979) or fall (28%, n = 970) (Fig. 9).

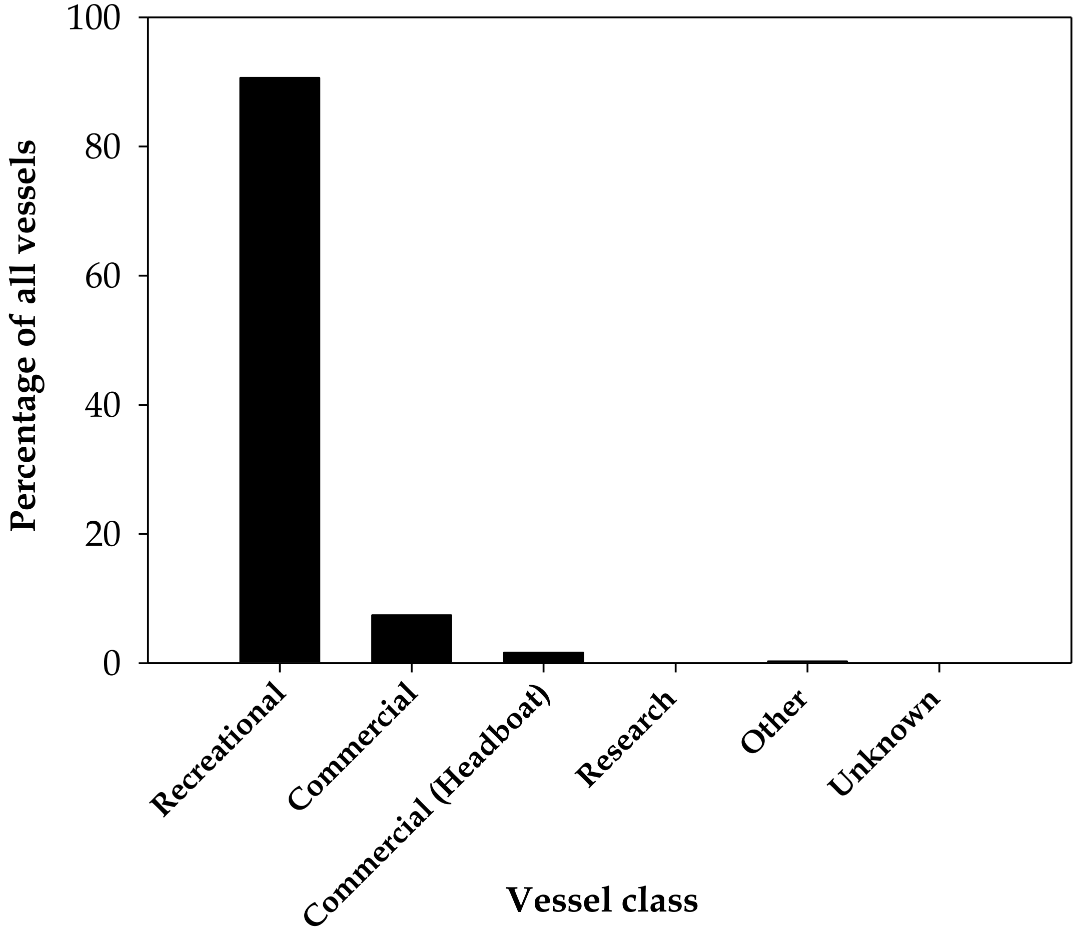

Figure 4. Percentage of vessels within each vessel class category for all vessels in the southeast Florida study area.

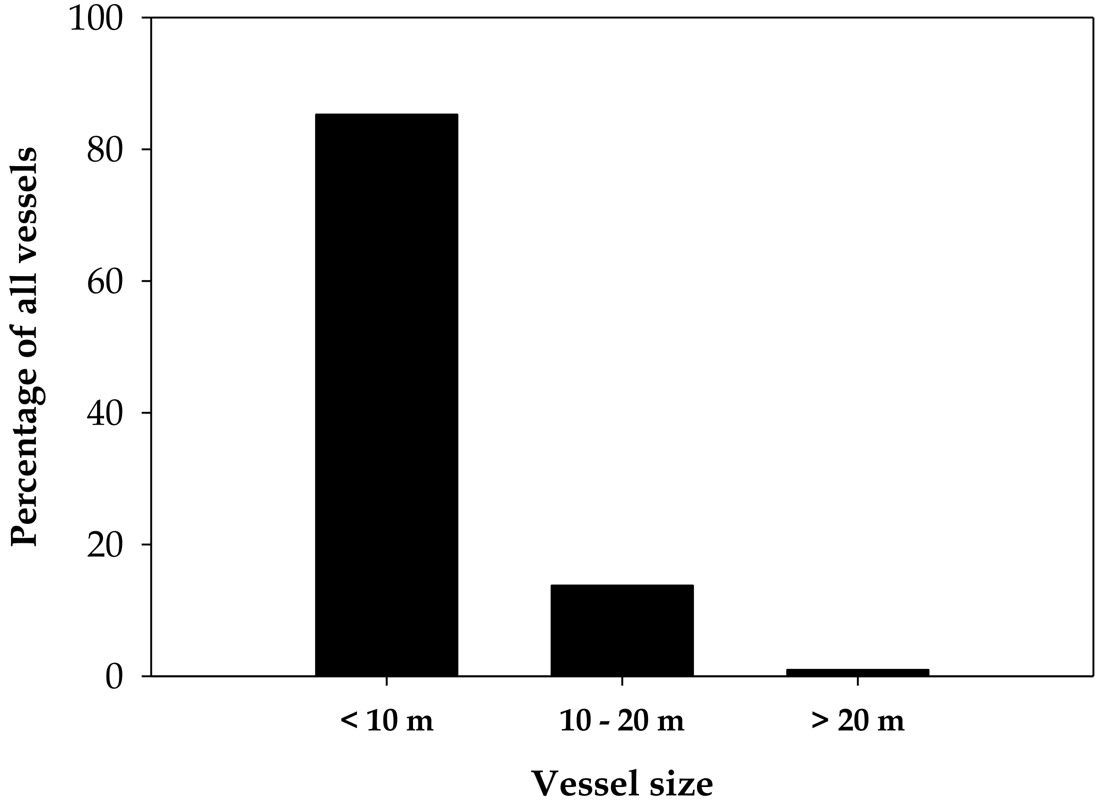

Figure 5. Percentage of vessels within each vessel size category, in meters, for all vessels in the southeast Florida study area.

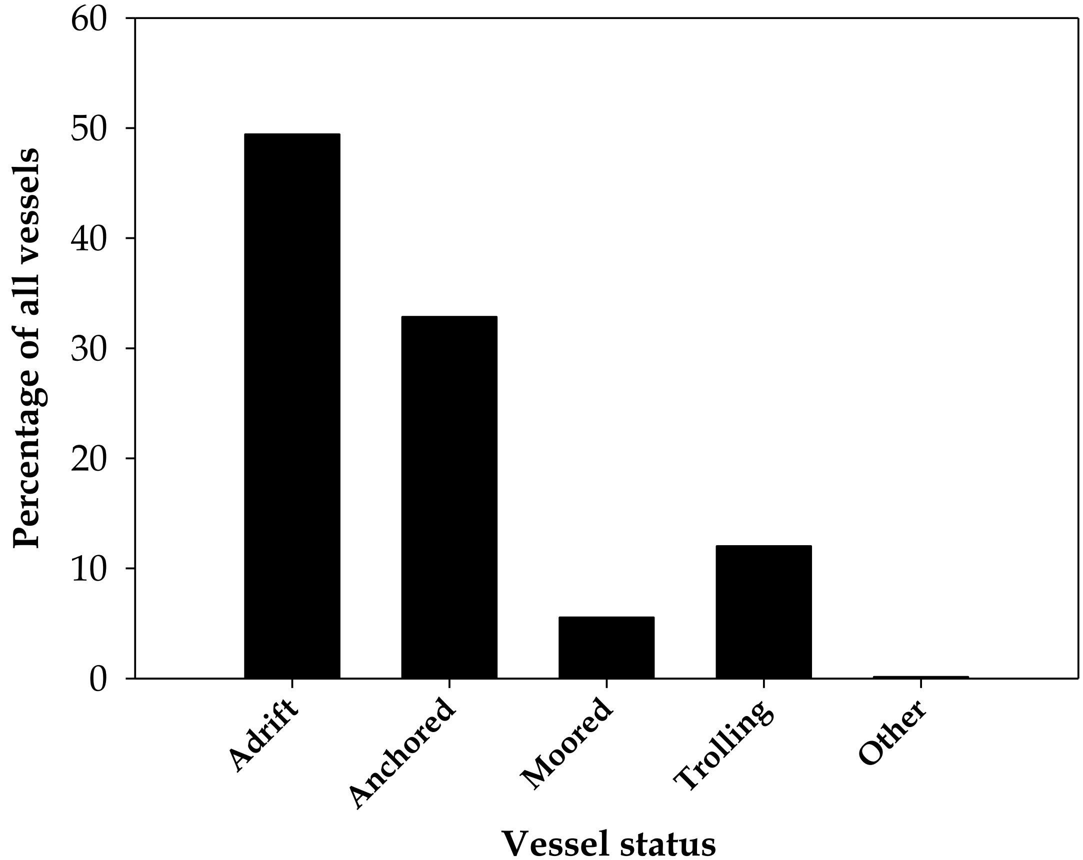

Figure 6. Percentage of vessels within each vessel status category for all vessels in the southeast Florida study area.

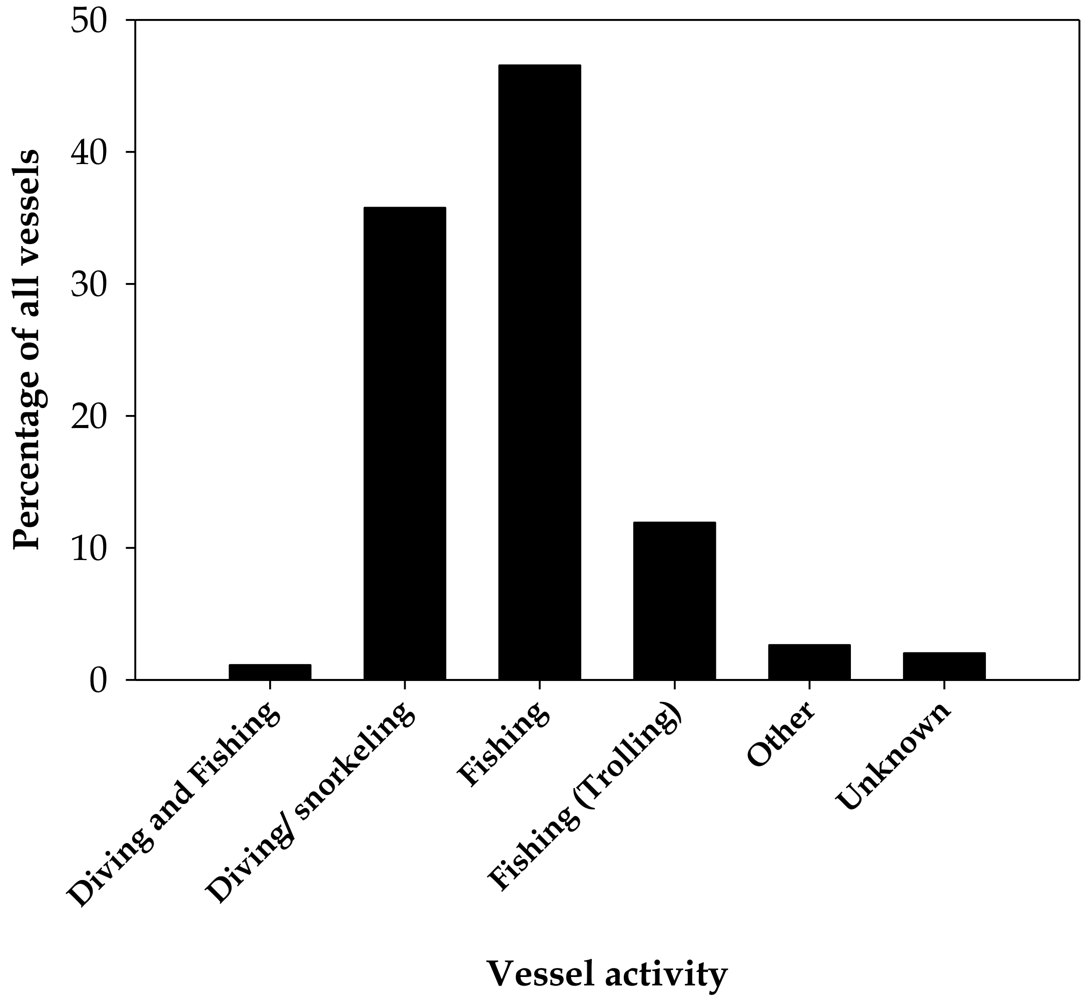

Figure 7. Percentage of vessels within each vessel activity category for all vessels in the southeast Florida study area.

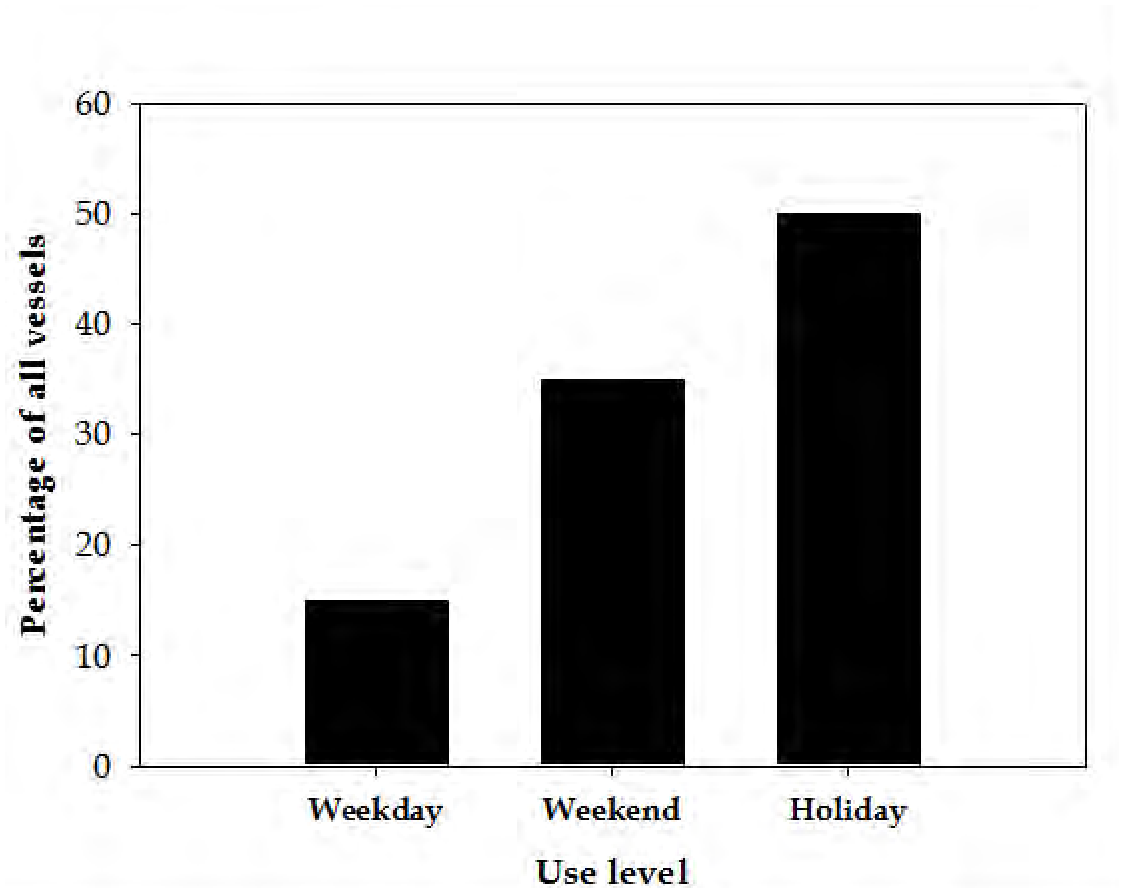

Figure 8. Percentage of vessels within each use level for all vessels in the southeast Florida study area.

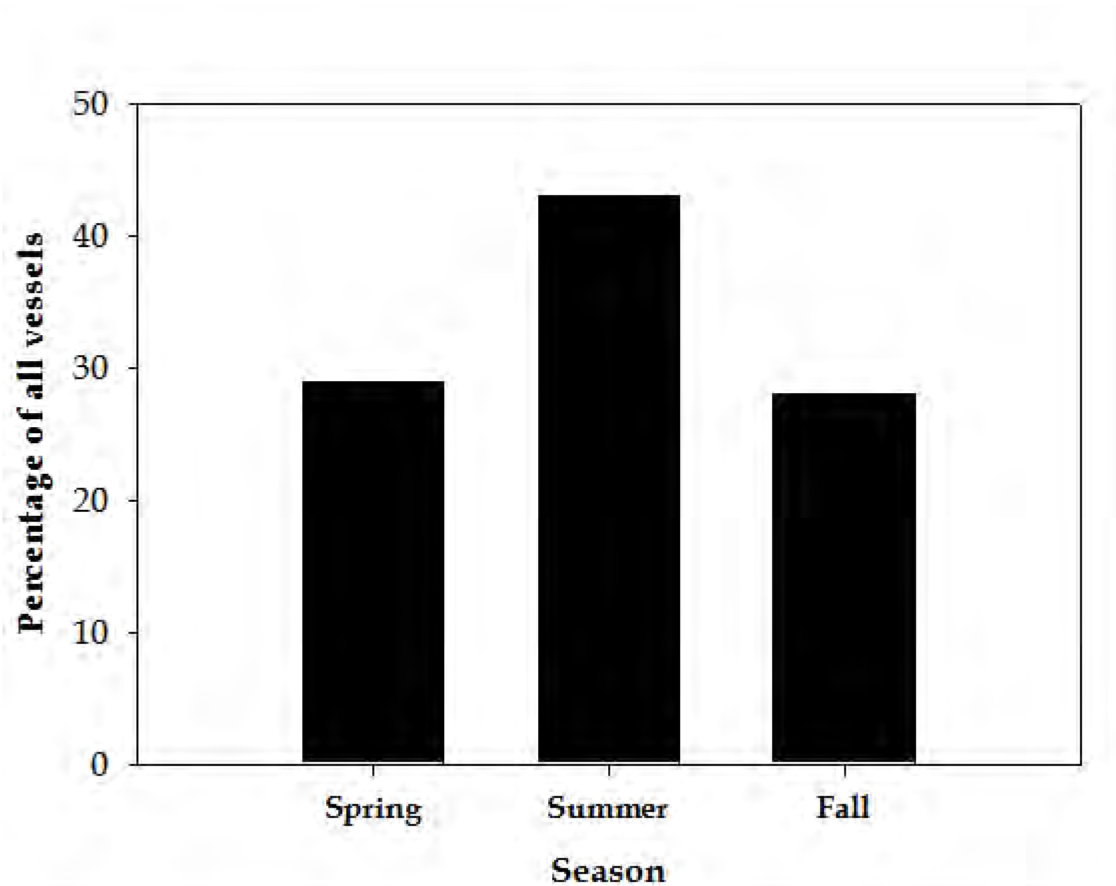

Figure 9. Percentage of vessels within each season for all vessels in the southeast Florida study area.

4.1.2 Vessel categories by county

Even figure numbers between 10 – 16 show the vessels in each category and county as a percentage of the total number of vessels observed in the study region (n = 3,406). Odd figure numbers between 11 – 17 show the vessels in each category and county as a percentage of the vessels observed within the county.

The relative percentages within each vessel class (Fig. 10) and size (Fig. 12) did not differ dramatically between counties. However, the magnitude within Martin County was far less than the other three counties. When these data were plotted as percentages of vessels within each county this difference is not present (Fig. 11, 13).

The greatest number of anchored vessels of all those in the study area were observed in Miami-Dade County (14.8%) (Fig. 14) and this was the only county in which anchoring exceeded vessels adrift. The greatest percentage of moored vessels were observed in Broward County (5.2%). The greatest magnitude of vessels observed adrift was in Palm Beach County (21.3%). The percentage of trolling vessels increased from Miami-Dade through Palm Beach (2.3 – 5.3%), but then dropped off in Martin County (1.2%). These patterns remained similar when these data were plotted as percentages of vessels within each county (Fig. 15). The frequency of anchoring within Miami-Dade (52%, n = 506) was equal to the frequency in Broward County (28%, n = 301) and Palm Beach County (22%, n = 252) combined (Fig. 15). The frequency of anchoring observed in Martin County (35%) also was higher than Broward and Palm Beach, but the magnitude was much lower (n = 61).

Diving, fishing, and diving and fishing categories comprised most (95%) of the activities in all counties (Fig. 16). Fishing exceeded diving in all counties except Broward, and fishing exceeded diving by a large margin in Palm Beach County. Again, the relative percentages of activities in Martin County were similar to Palm Beach, but the magnitude was much lower. These patterns remained similar when these data were plotted as percentages of vessels within each county - the Palm Beach and Martin County activity percentages were very similar (Fig. 17). The trends in diving/snorkeling (37% Miami-Dade versus 50% Broward) and fishing (52% Miami-Dade versus 34% Broward) activities were opposites of each other between Miami-Dade and Broward Counties.

The percentage of vessels observed in Miami-Dade and Broward counties during the use levels approximately doubled from weekdays to weekends and again from weekends to holidays (Fig. 18), but in Palm Beach County the holiday use was slightly less than the weekend use. Martin County followed a similar pattern to Palm Beach, but at a much lower magnitude.

Similar percentages of vessels were observed in the spring and fall in all counties (Fig. 19). In Miami-Dade, Broward, and Martin counties the percentage of vessels observed in the summer was much higher than spring or fall, but in Palm Beach County it was slightly less than either other season.

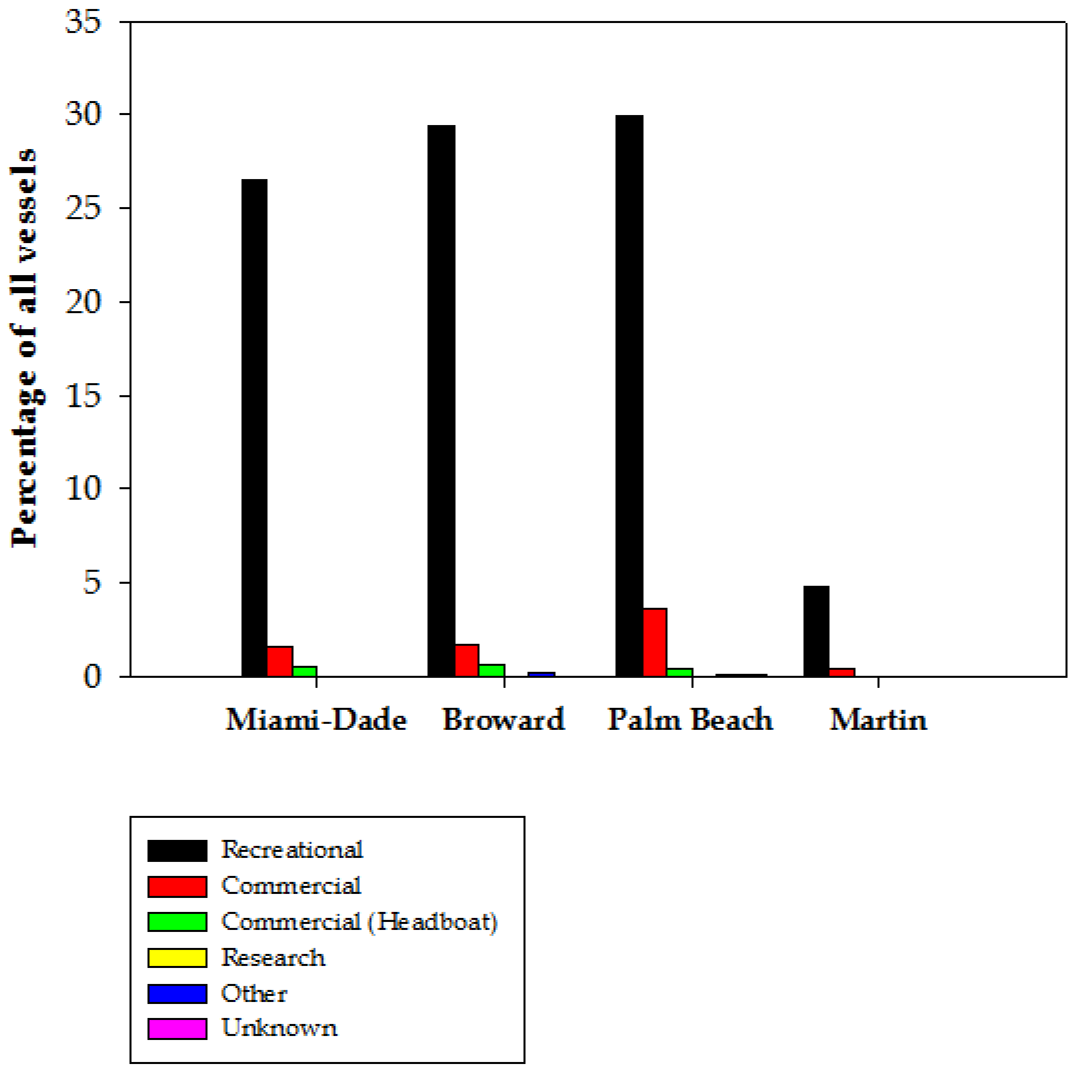

Figure 10. Vessels within each vessel class category and county as a percentage of all vessels in the southeast Florida study area.

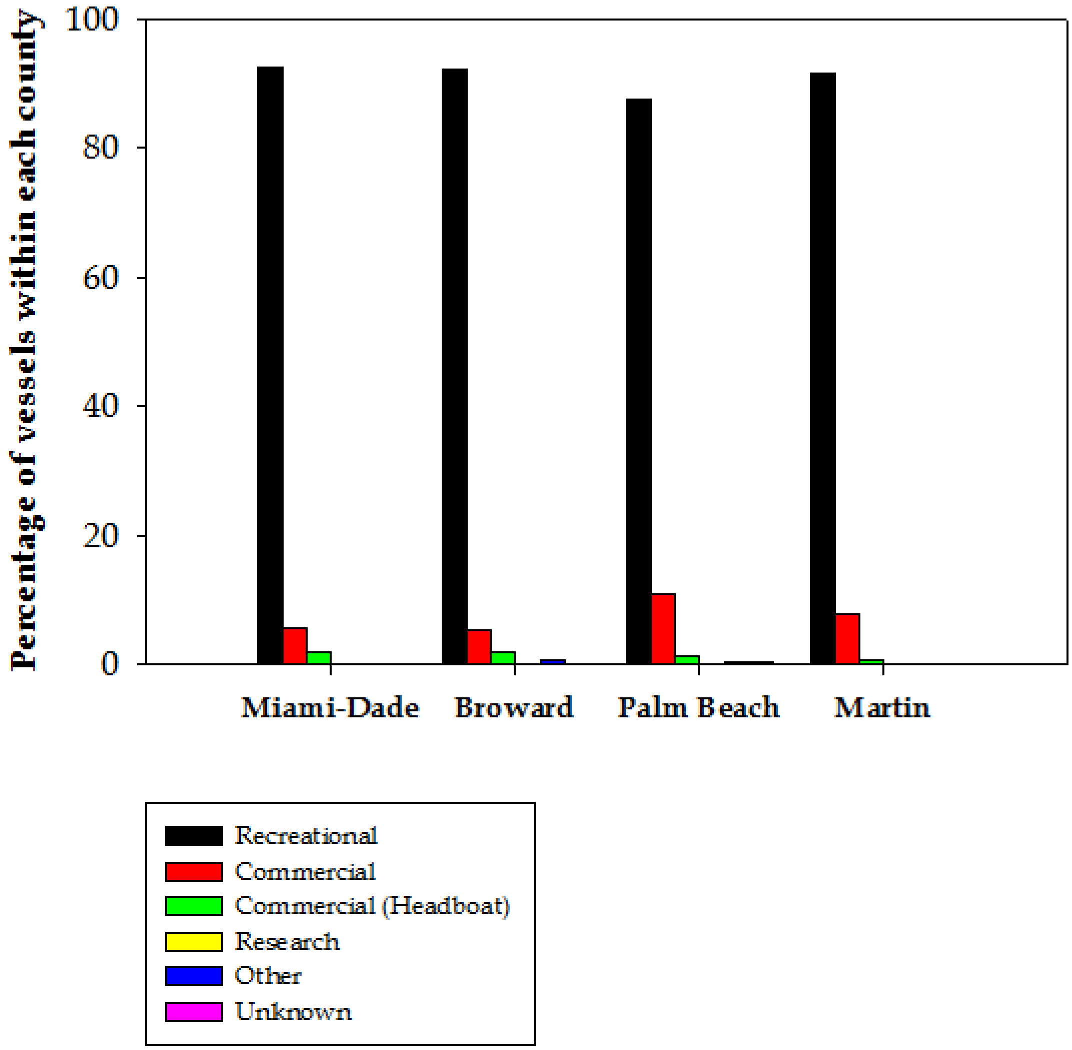

Figure 11. Vessels in each vessel class category as a percentage of the vessels in each county.

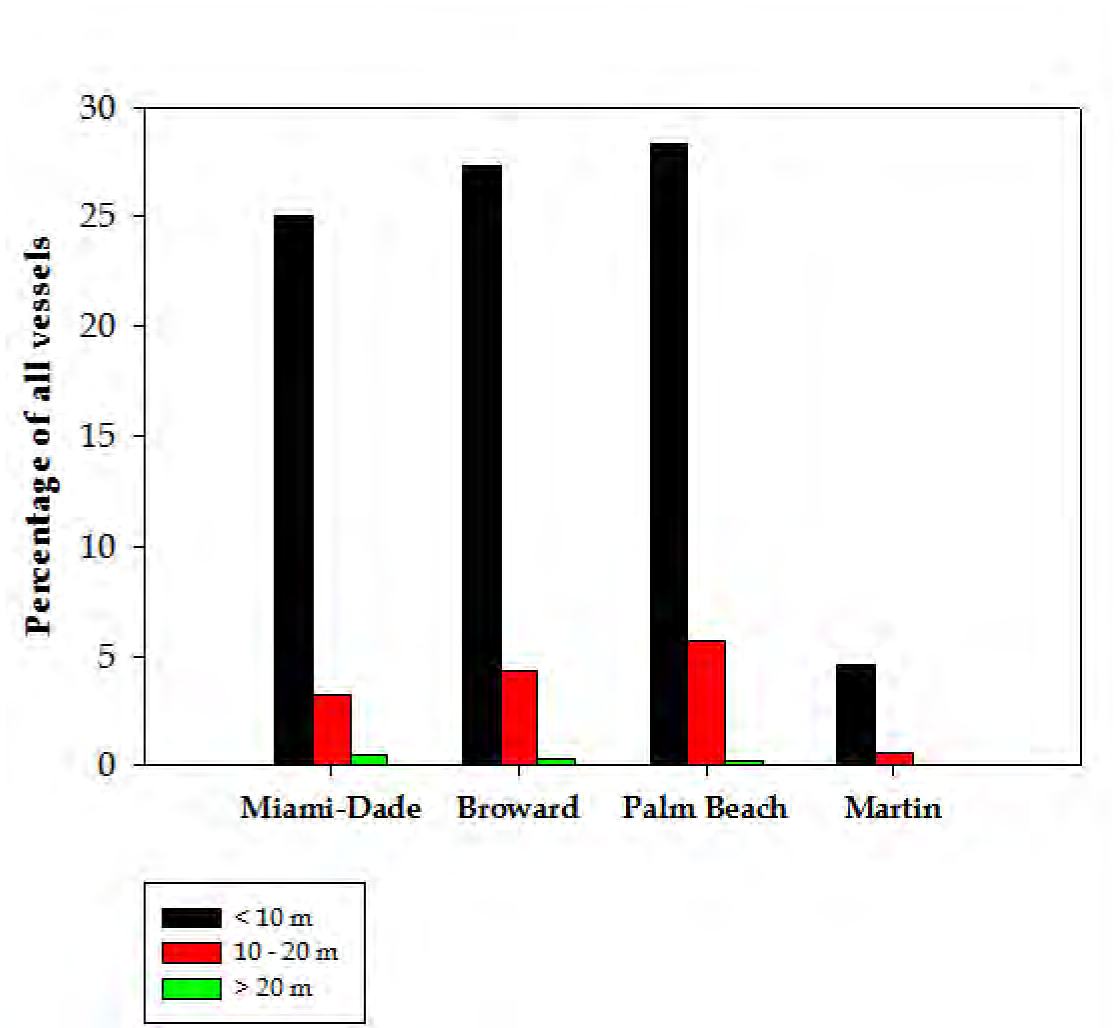

Figure 12. Vessels within each vessel size category and county as a percentage of all vessels in the southeast Florida study area.

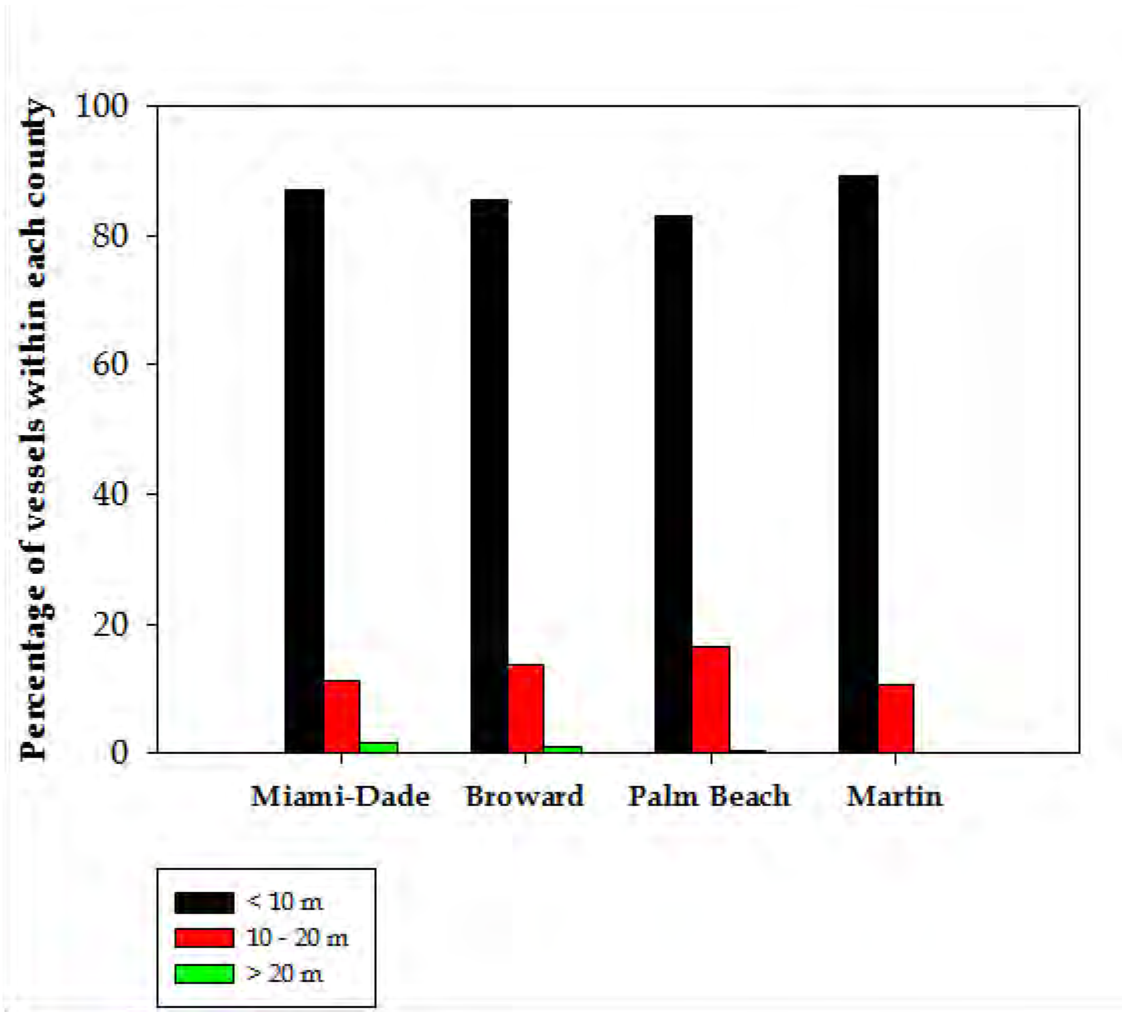

Figure 13. Vessels in each vessel size category as a percentage of the vessels in each county.

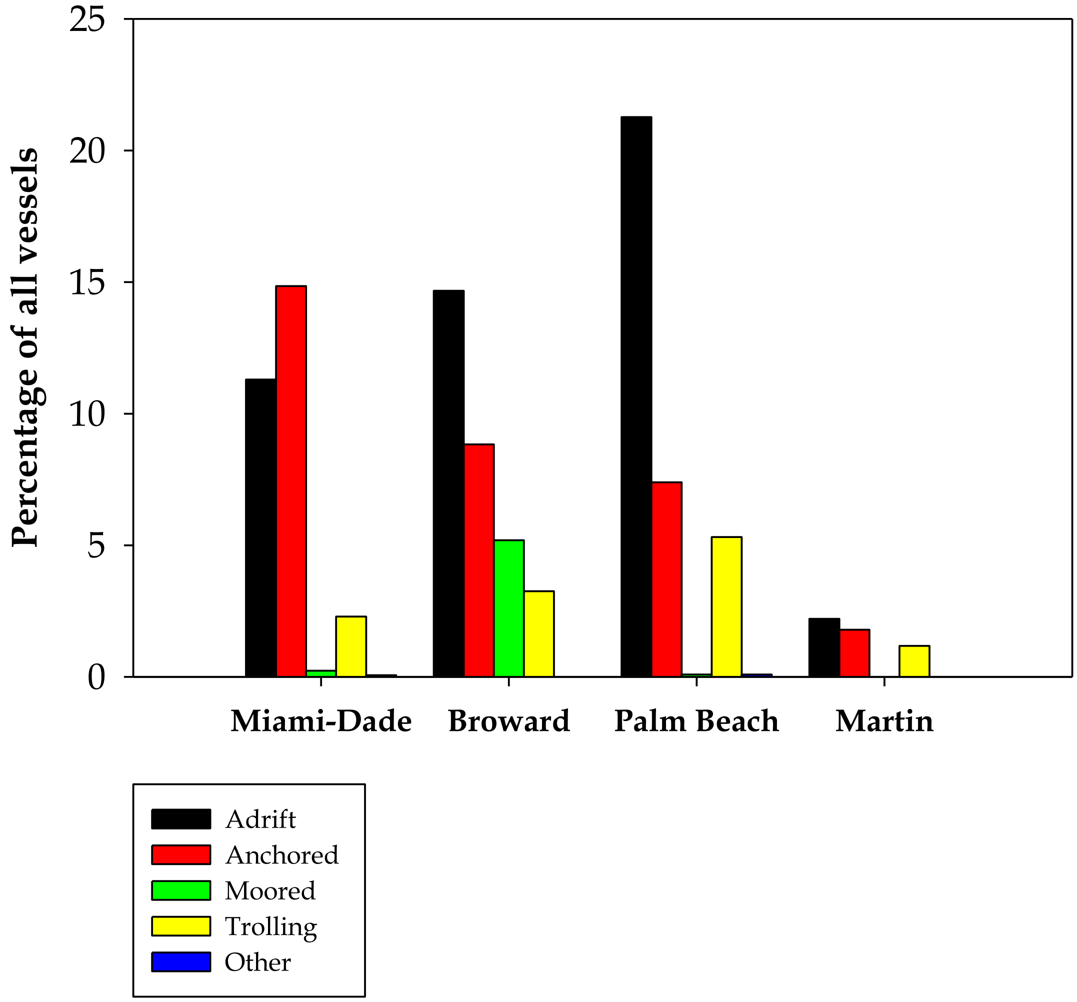

Figure 14. Vessels within each vessel status category and county as a percentage of all vessels in the southeast Florida study area.

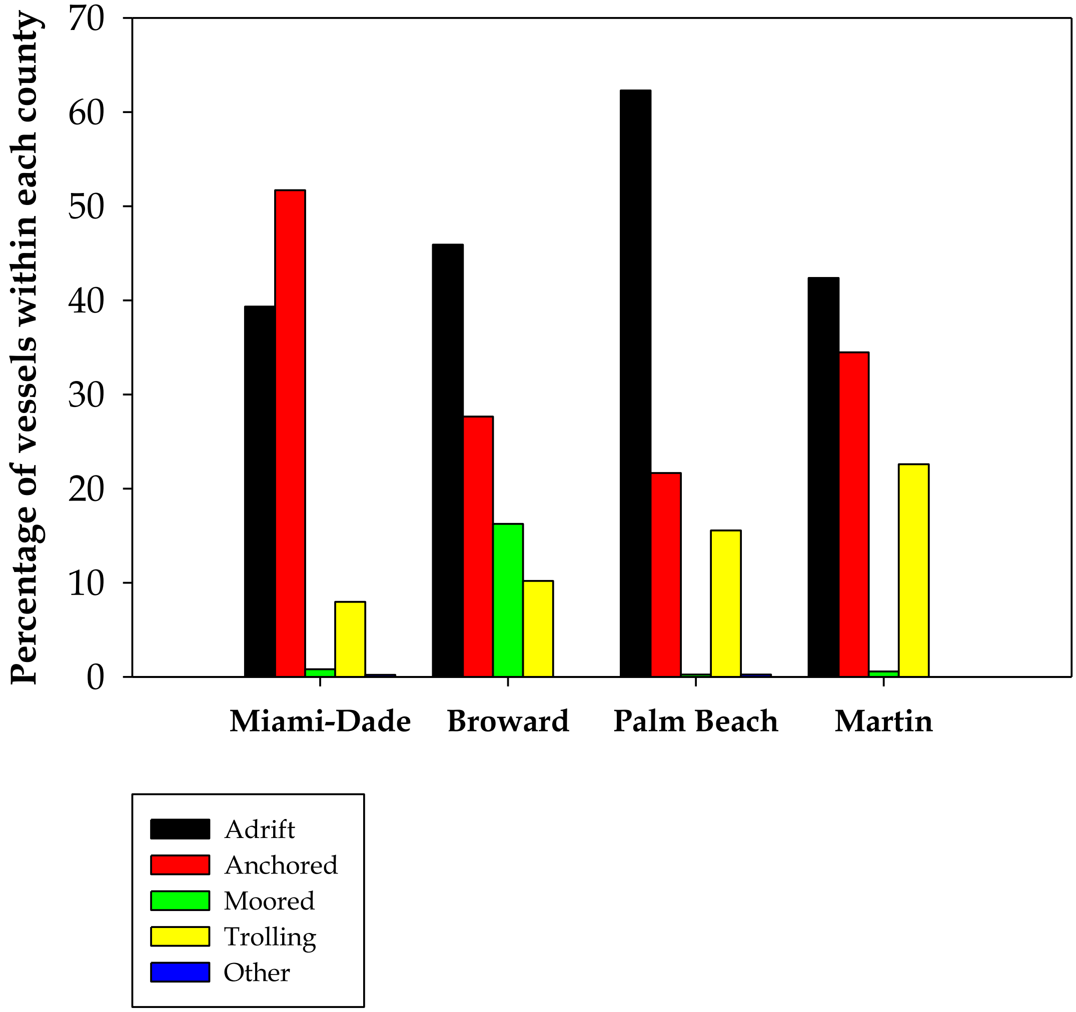

Figure 15. Vessels in each vessel status category as a percentage of the vessels in each county.

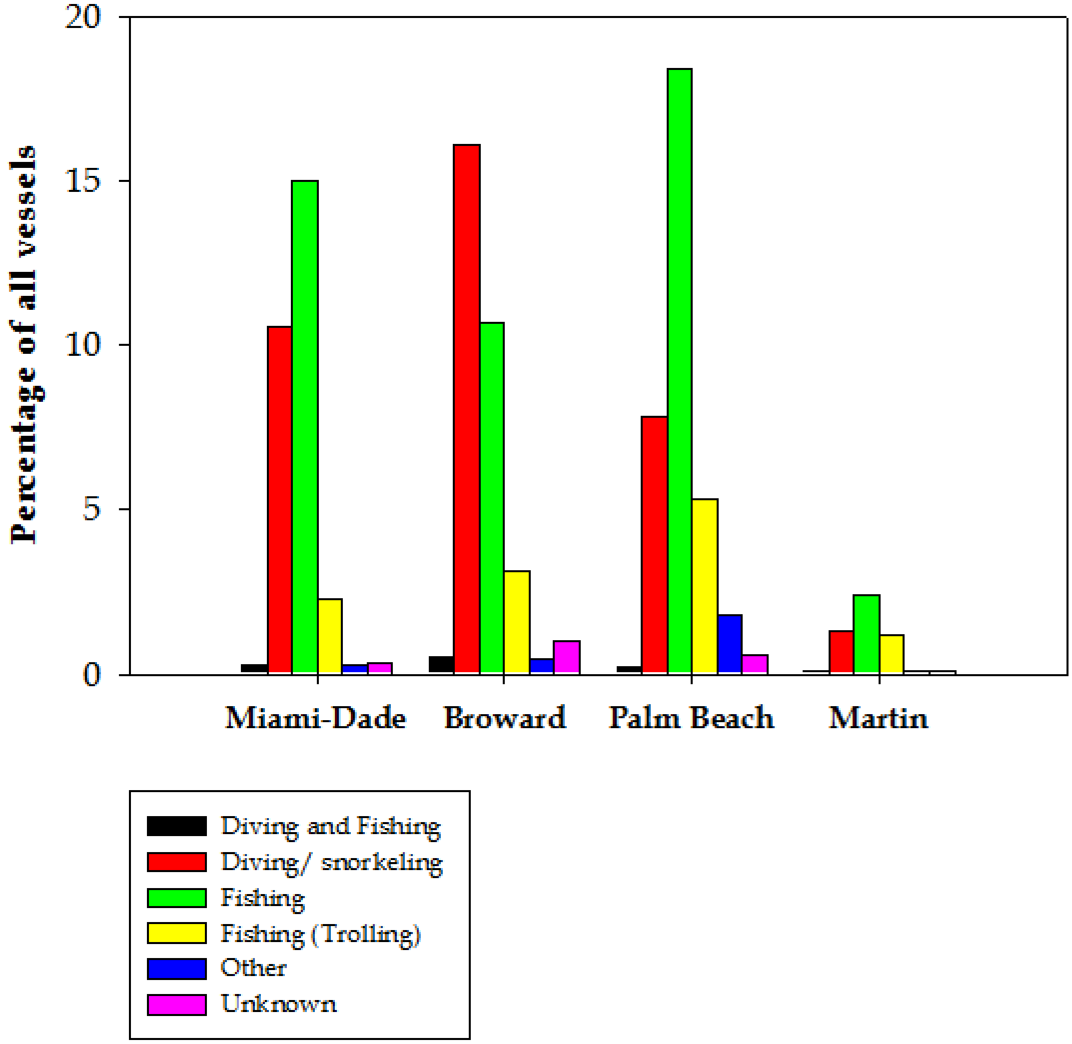

Figure 16. Vessels within each vessel activity category and county as a percentage of all vessels in the southeast Florida study area.

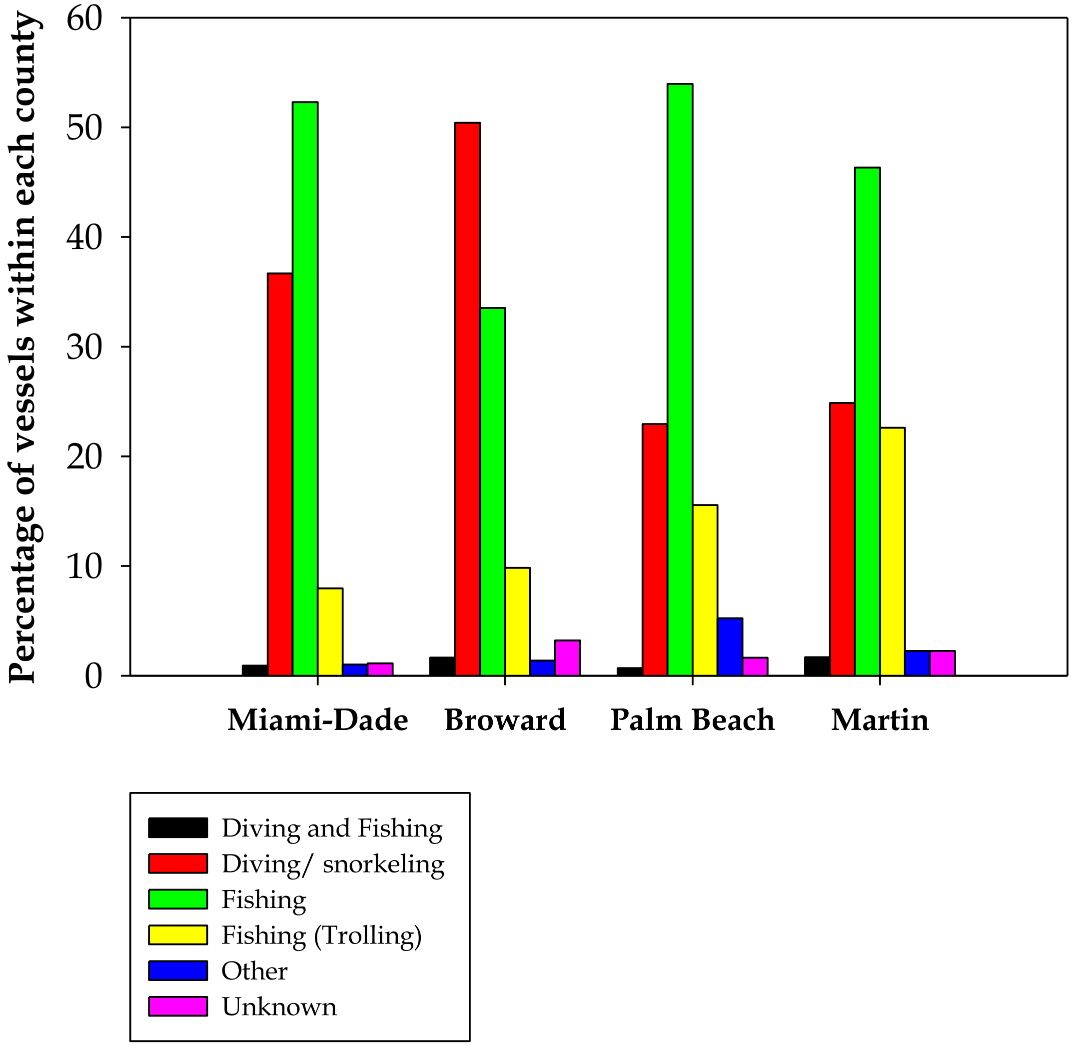

Figure 17. Vessels in each vessel activity category as a percentage of the vessels in each county.

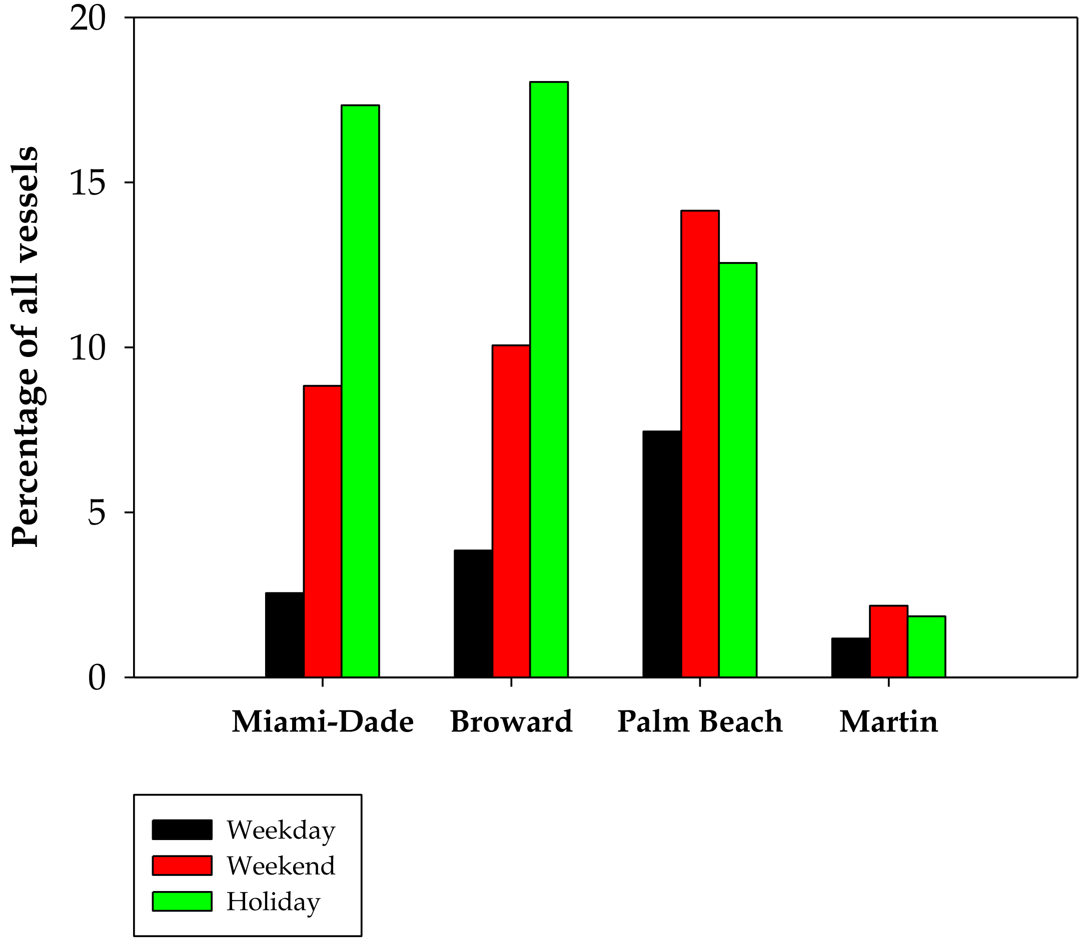

Figure 18. Vessels within each vessel use level and county as a percentage of all vessels in the southeast Florida study area.

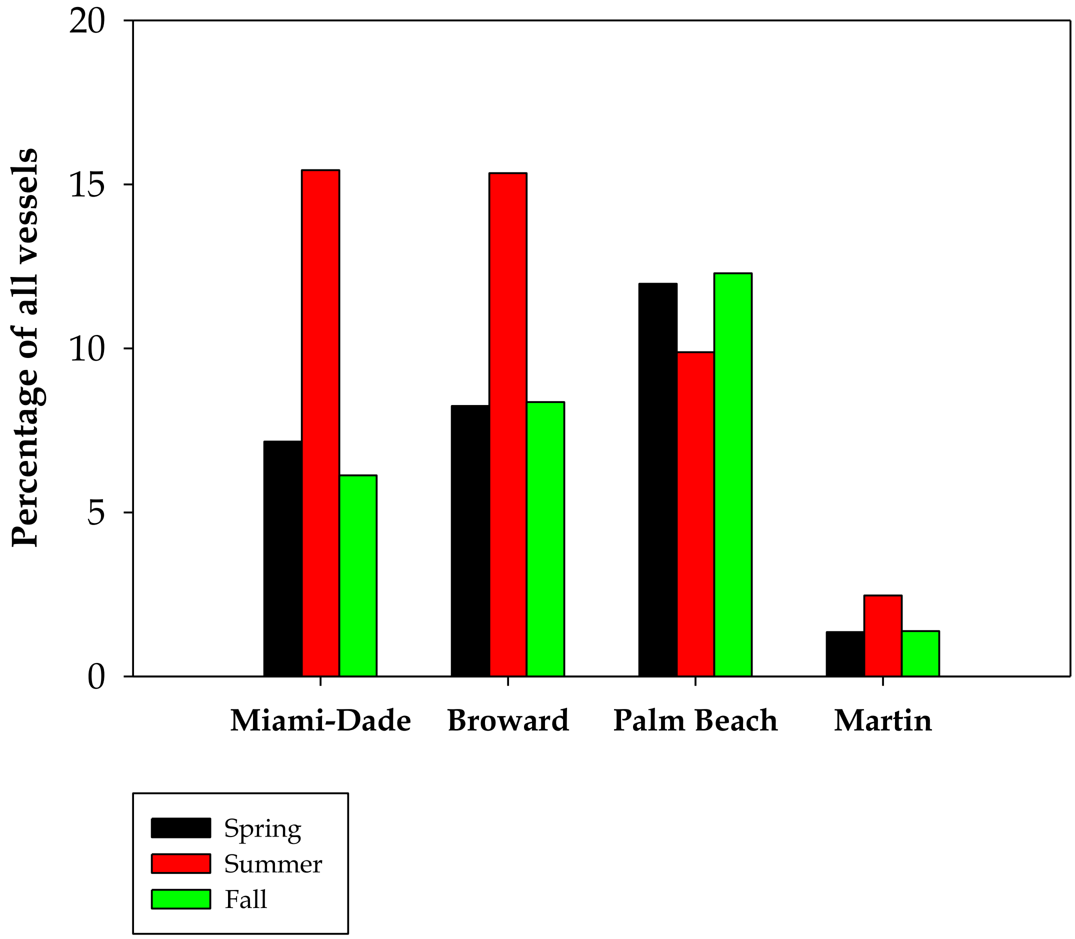

Figure 19. Vessels within each season and county as a percentage of all vessels in the southeast Florida study area.

Vessel category by use level

Figures 20 – 27 show the vessel categories separated by use level. For category versus use level perspective, each figure is shown first with the category on the x-axis and the use levels as colored bars (Fig. 20, 22, 24, and 26). In the second of each figure they are reversed (Fig. 21, 23, 25, and 27). The statistical relationships between the use levels and data categories are described in section 4.2 below.

Recreational activities dominated all of the use levels (Fig. 20, 21). However, commercial activities were highest on weekdays and recreation lowest on weekdays. The other activities were infrequently observed during all use levels.

The relative vessel sizes were similar during all use periods (Fig. 22, 23). However, there were significantly ($p = 0.0132$) more vessels > 20 m compared to those 10 – 20 m observed on weekdays (Table 6).

Vessel status and activity varied considerably with use level (Fig. 24 – 27) (Table 7, 8). These relationships are described in section 4.2.

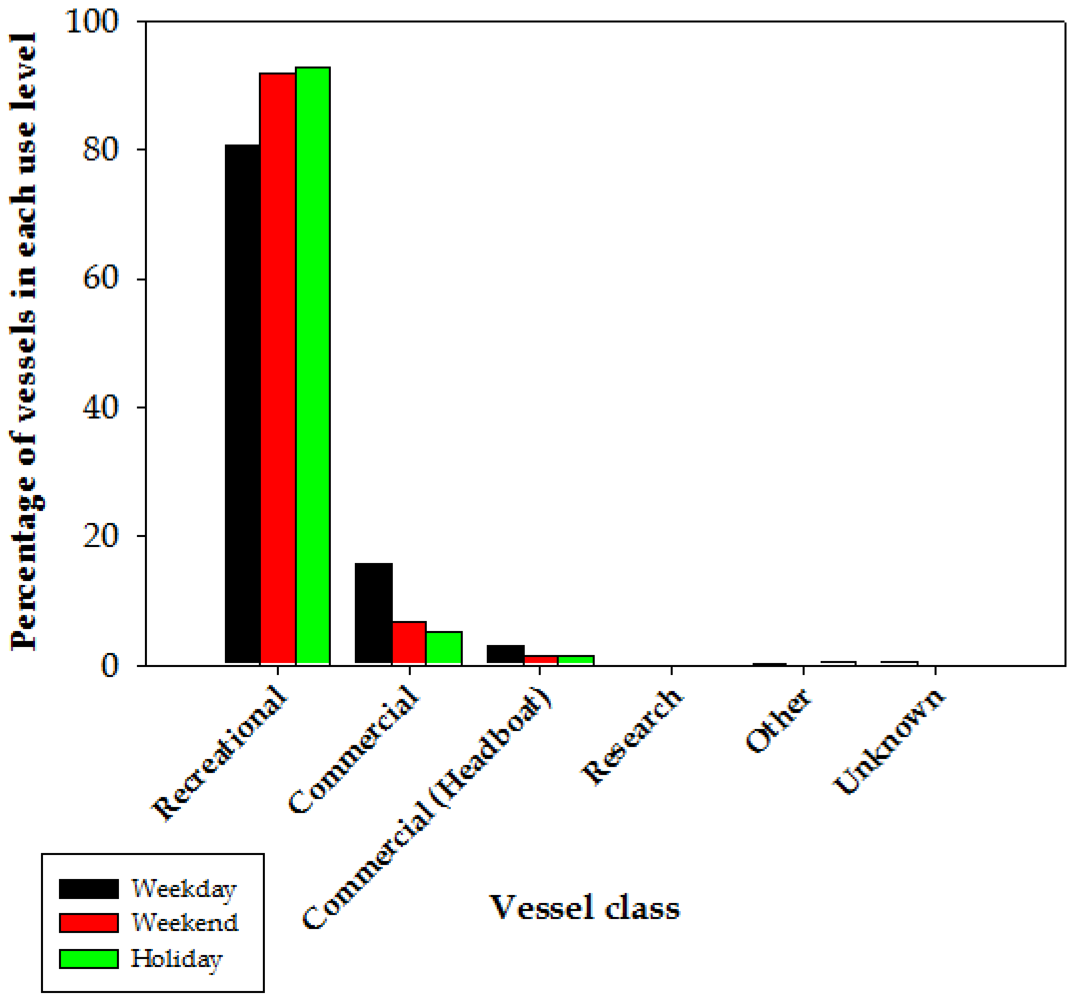

Figure 20. Percentage of vessels in each vessel class category by survey use level.

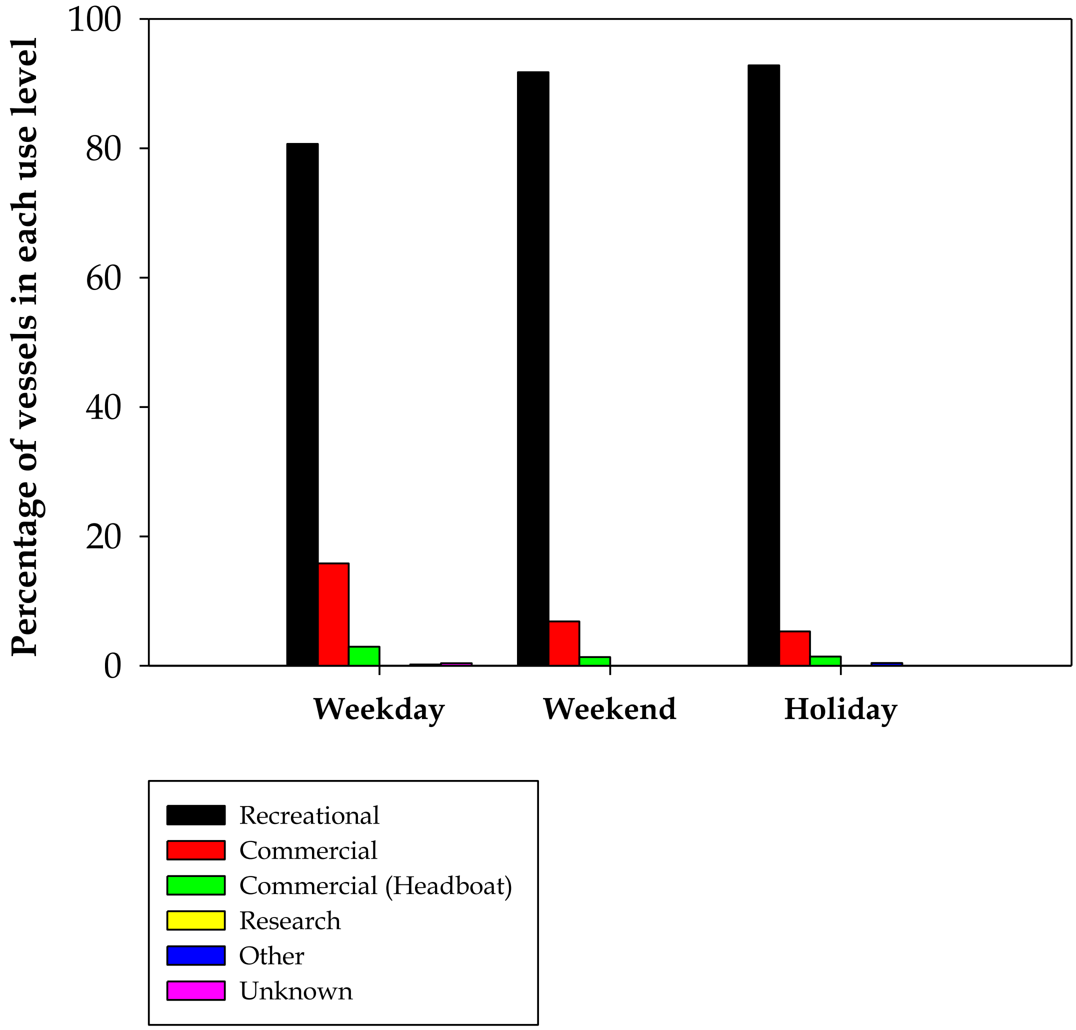

Figure 21. Percentage of vessels in each vessel class category by survey use level.

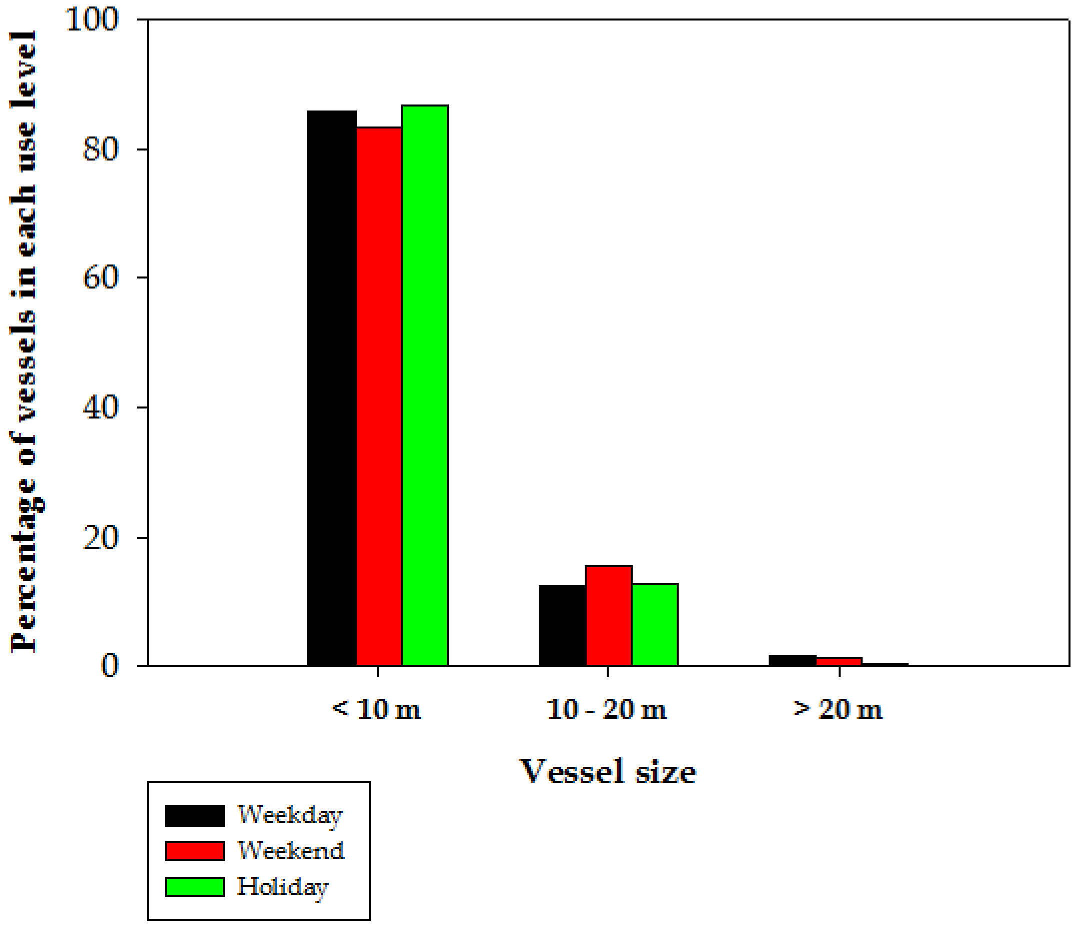

Figure 22. Percentage of vessels in each vessel size category by survey use level.

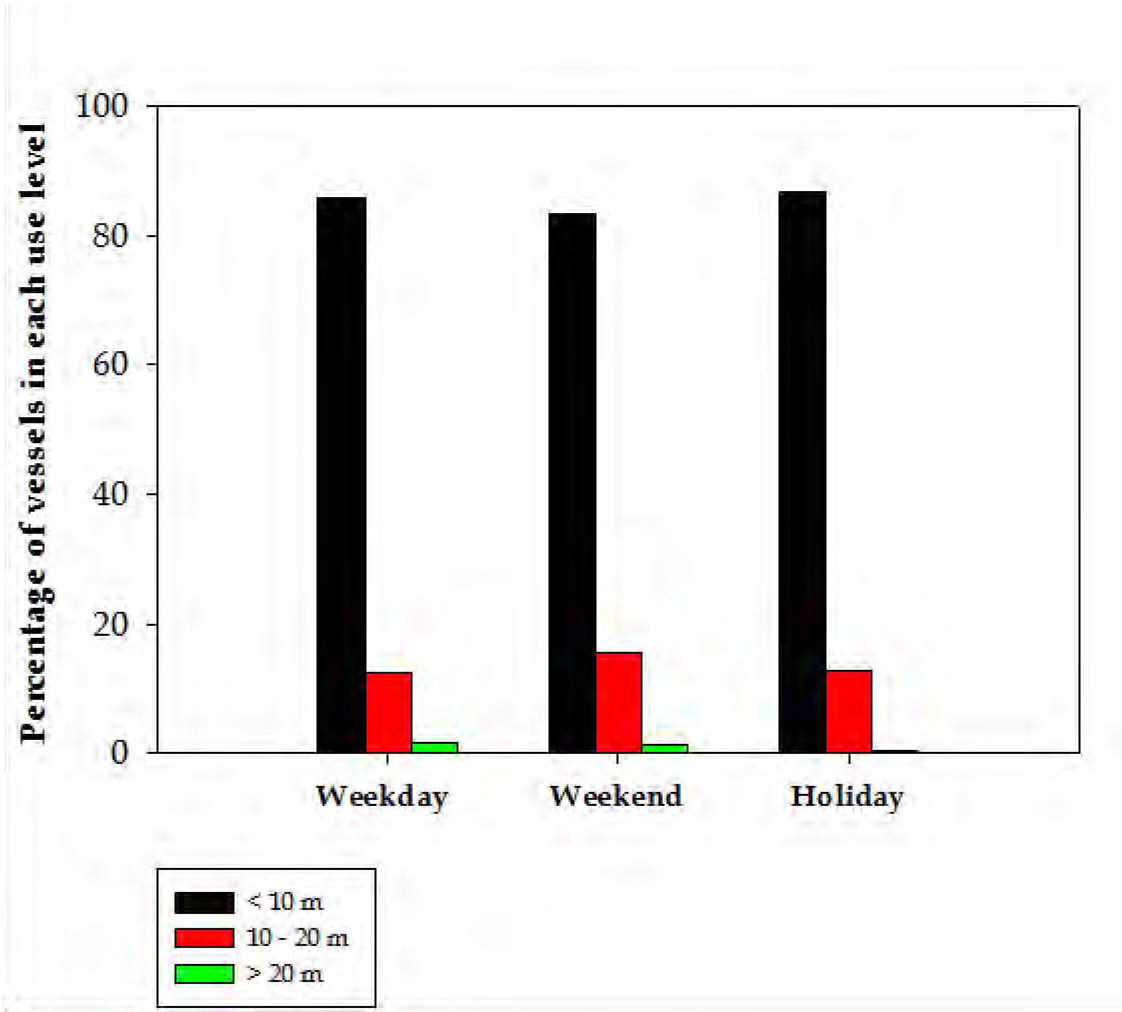

Figure 23. Percentage of vessels in each vessel size category by survey use level.

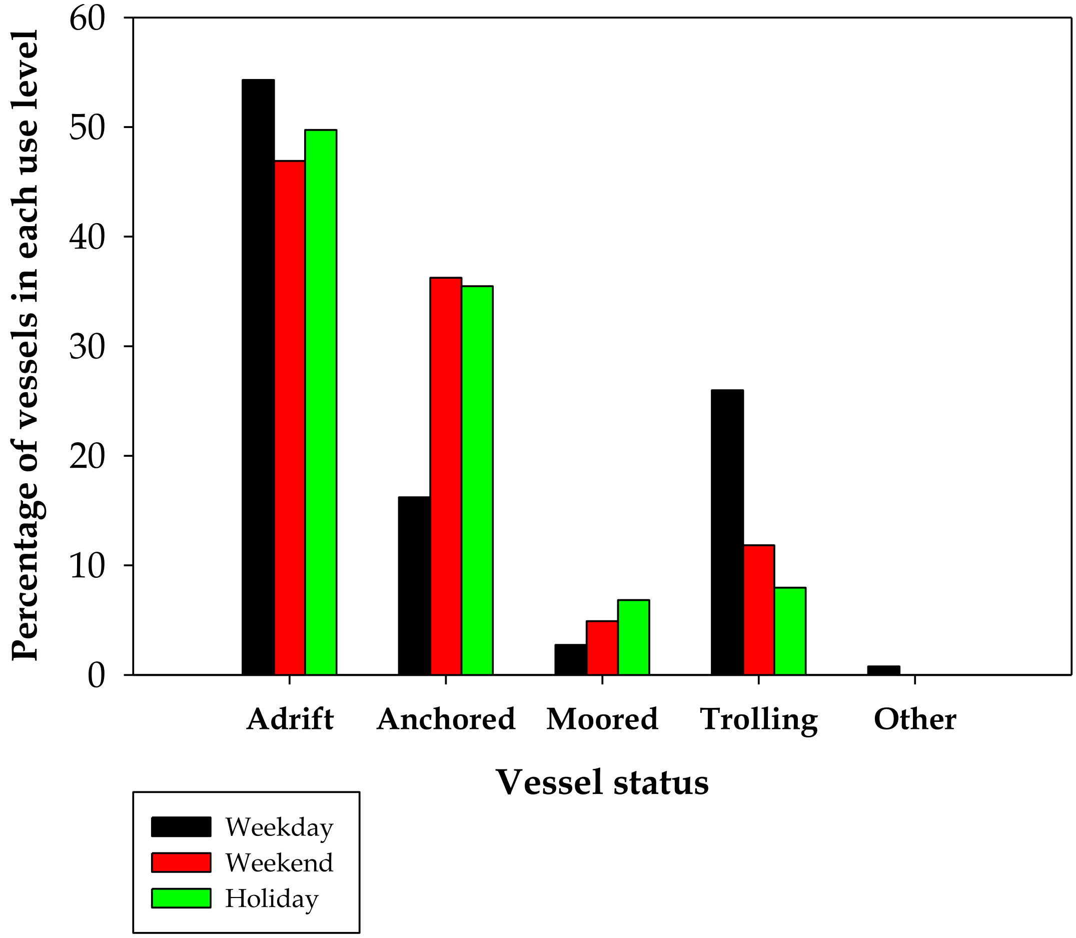

Figure 24. Percentage of vessels in each vessel status category by survey use level.

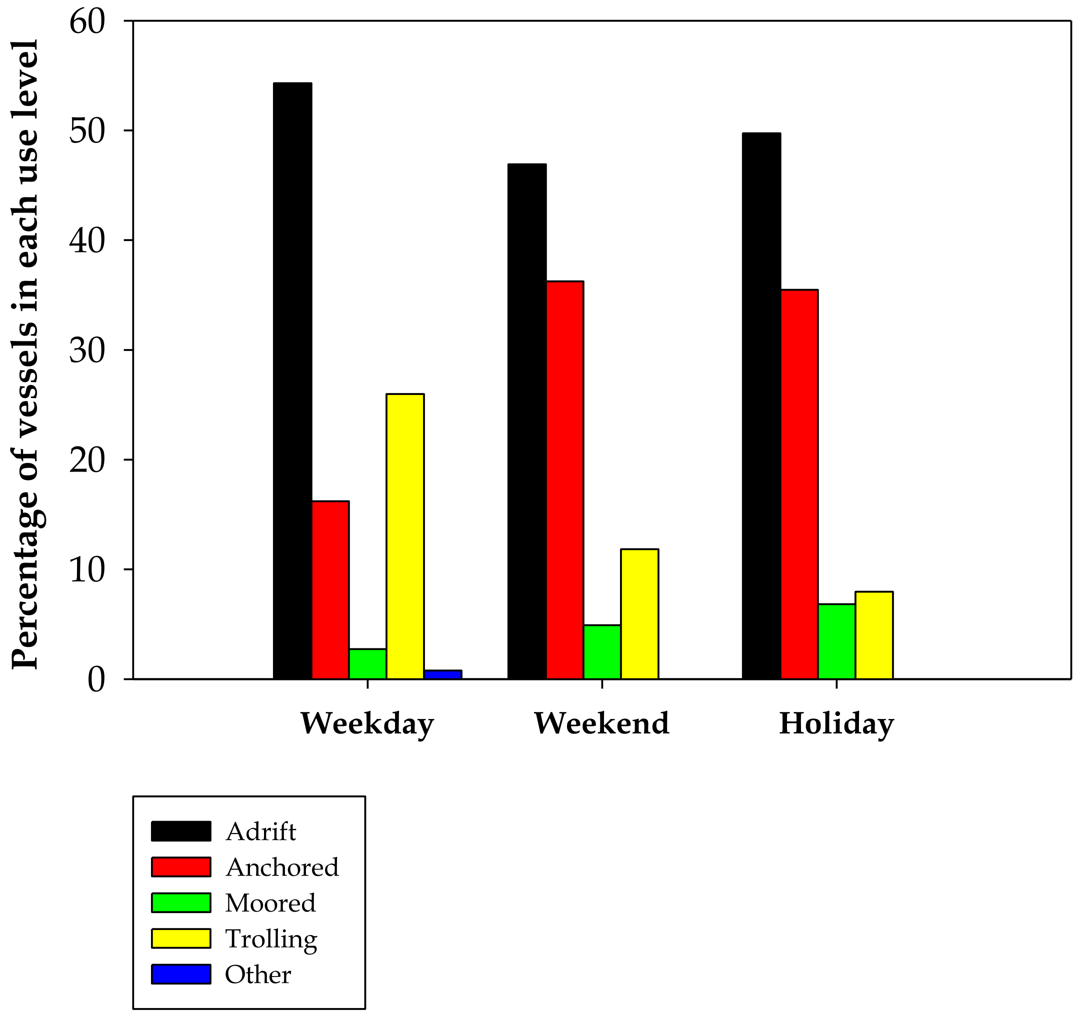

Figure 25. Percentage of vessels in each vessel status category by survey use level.

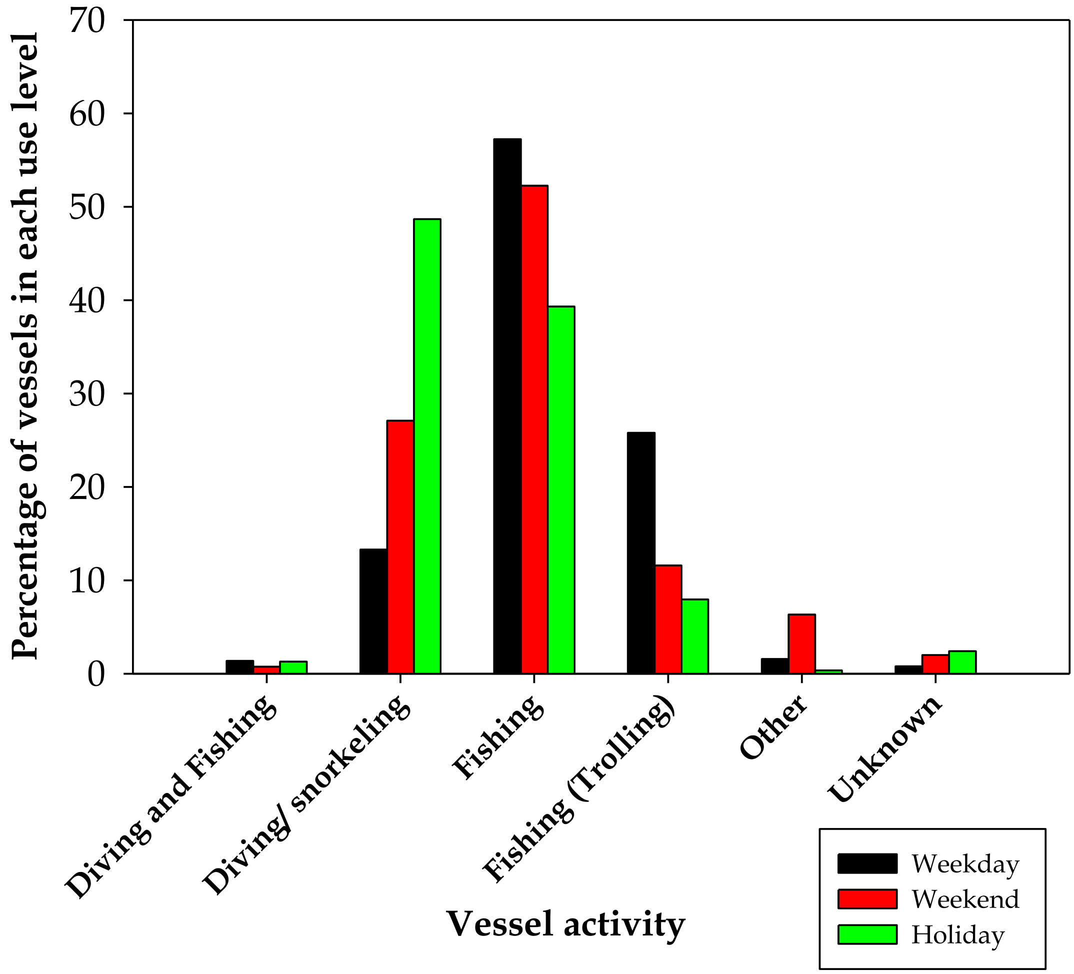

Figure 26. Percentage of vessels in each vessel activity category by survey use level.

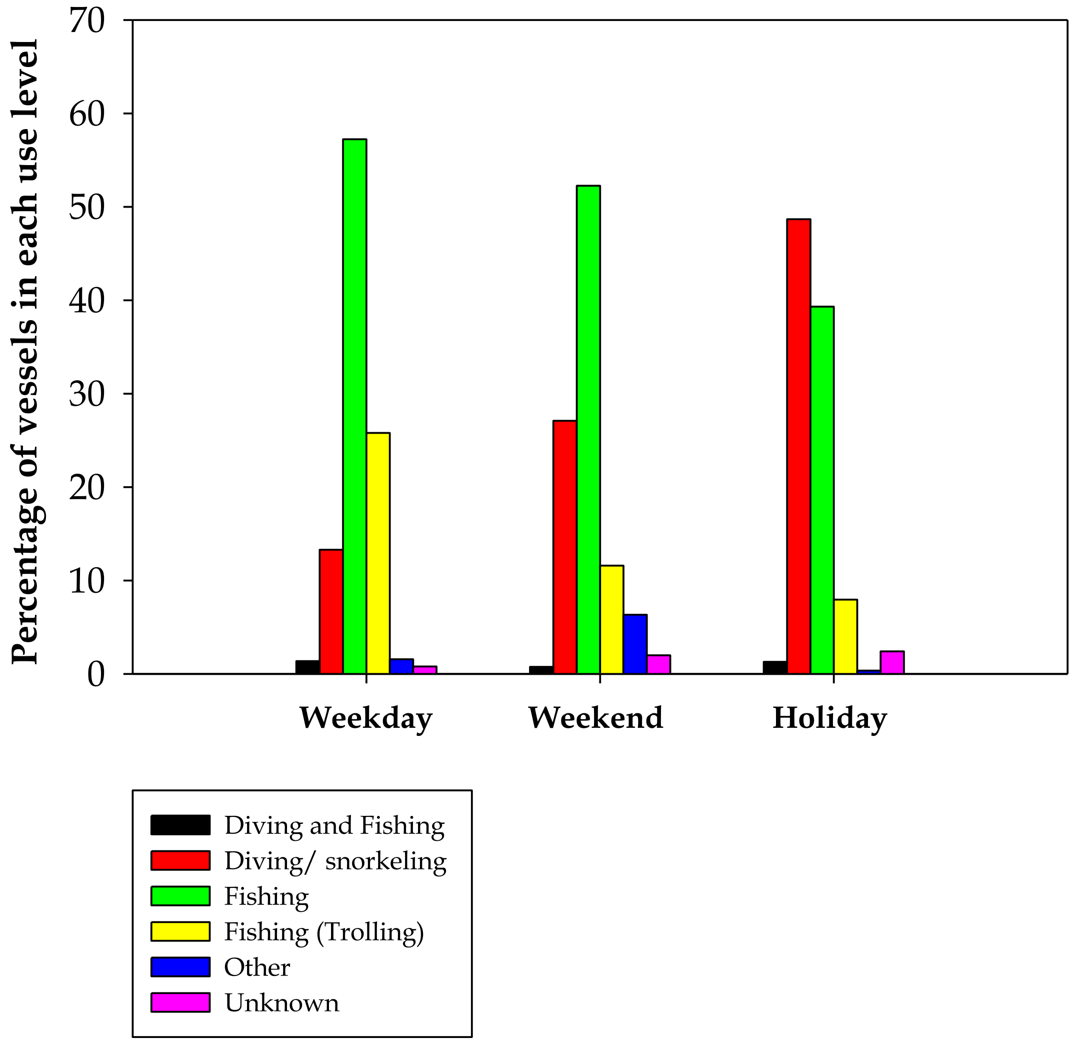

Figure 27. Percentage of vessels in each vessel activity category by survey use level.

When only anchored vessels (n = 1,120) were considered (Fig. 28 – 30) some clear patterns emerged. Greater than 90% of all anchored vessels were of the recreational class (Fig. 28) and > 90% were < 10 m estimated length. However, the activity undertaken by anchored boaters was largely split between fishing and diving/snorkeling; the two combined for nearly 90% of the activity of anchored vessels.

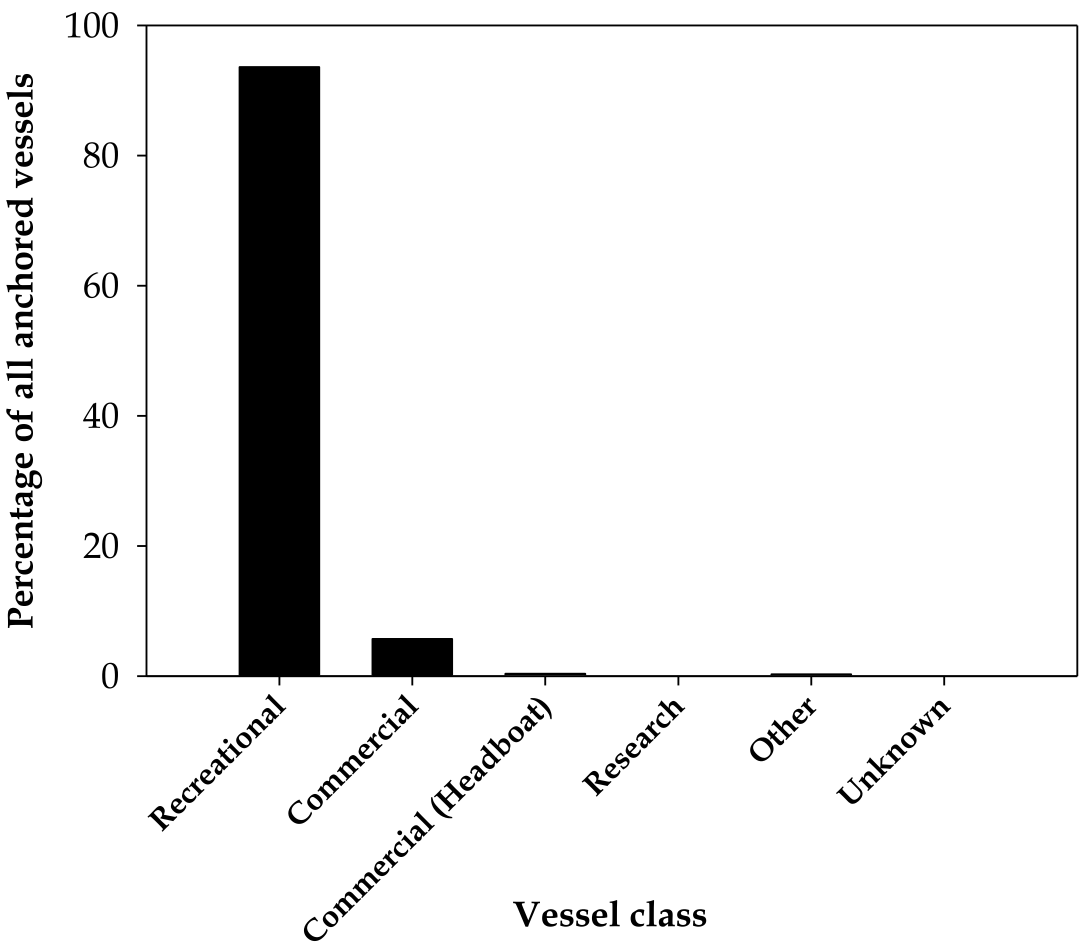

Figure 28. Percentage of anchored vessels in each vessel class category.

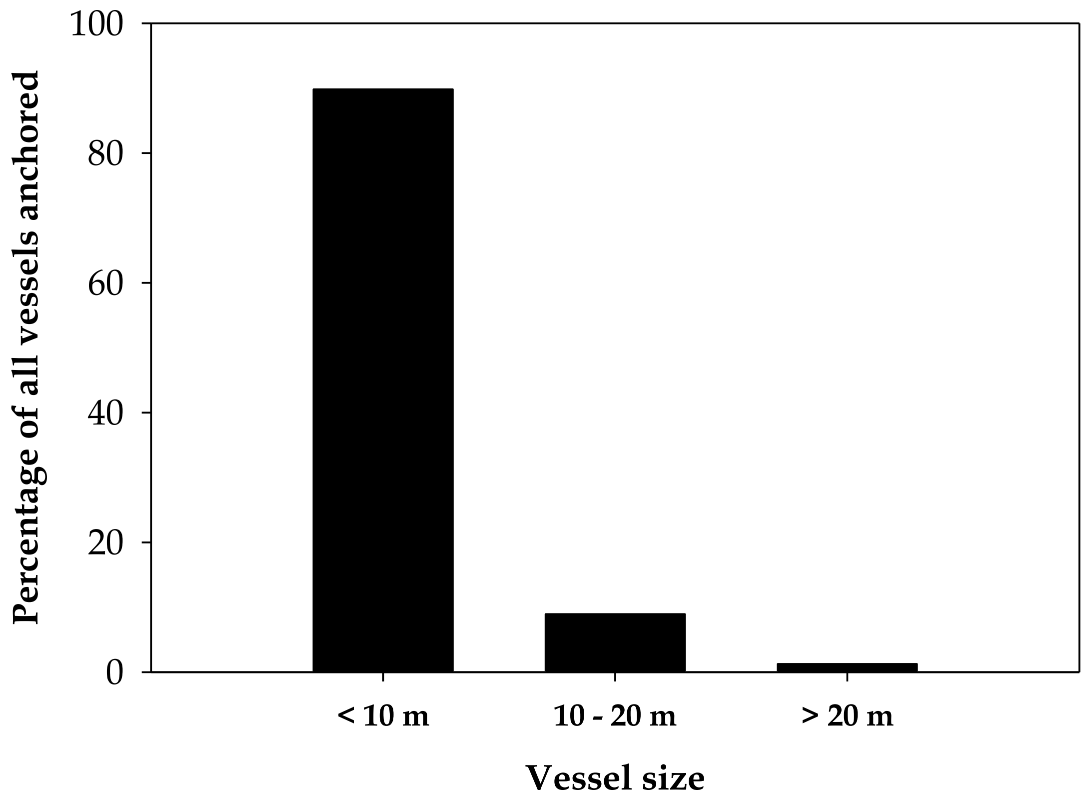

Figure 29. Percentage of anchored vessels in each vessel size category.

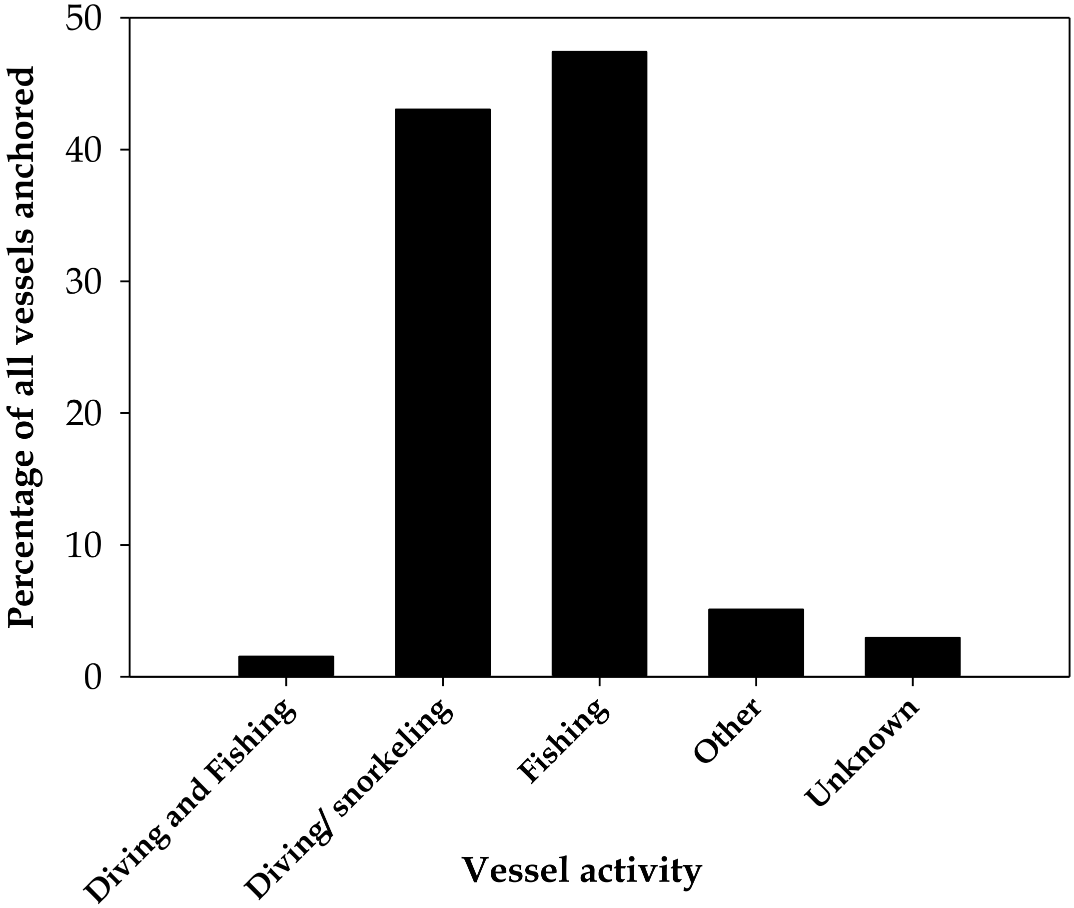

Figure 30. Percentage of anchored vessels in each vessel activity category. Fishing (Trolling) was not included as it requires the vessel to be moving (not anchored).

4.2 Contingency table analyses of relationships between data categories

The vessel activity and status were significantly dependent on vessel class (Table 2). Commercial vessels were more often fishing than diving/snorkeling ($p = 0.0436$) and were much less likely to be anchored ($p < 0.001$).

Table 2. Contingency table analysis of the relationship between vessel class and vessel activity and between vessel class and vessel status for the southeast Florida region.

Factors	df	Likelihood Ratio X^2	P	Outcome
Class (Recreational, commercial) Activity (Fish, Dive/snorkel)	3,201	3.131[F]	**0.0436**	Commercial > fishing
Class (Recreational, commercial) Status (Anchored, not anchored)	3,218	29.167[F]	**<0.001**	Recreational > anchoring

P-values in **bold** represent a significant difference between treatment groups.
[F] Denotes that a Fisher's Exact test was used in the analysis of a 2x2 contingency table.

Vessel activity and status were also dependent on vessel size (Tables 3 and 4). Vessels 10 – 20 m in length were more often diving/snorkeling than either those < 10 m or > 20 m ($p < 0.001$). However, vessels > 20 m were fishing significantly more often than those < 10 m ($p < 0.001$). Vessels < 10 m and vessels > 20 m were found anchored more often than those 10 – 20 m ($p < 0.001$ and $p = 0.007$, respectively) . However, there were only 32 vessels > 20 m observed during the study, so this result is based on a small sample size. Many of these vessels were large tankers and cargo ships anchored outside of Port Everglades and the Port of Miami.

Table 3. Contingency table analysis of the relationship between vessel size and activity for the southeast Florida region.

Factors	df	Likelihood Ratio X^2	P	Outcome
Size (< 10 m, 10 - 20 m, > 20 m) Activity (Fish, Dive/snorkel)	3,211	22.208	**<0.001**	
Size (< 10 m, 10 - 20 m) Activity (Fish, Dive/snorkel)	3,191	3.042[F]	**0.0451**	< 10 m > fishing
Size (10 - 20 m, > 20 m) Activity (Fish, Dive/snorkel)	465	21.117[F]	**<0.001**	> 20 m > fishing
Size (< 10 m, > 20 m) Activity (Fish, Dive/snorkel)	2,765	18.765[F]	**<0.001**	> 20 m > fishing

P-values in **bold** represent a significant difference between treatment groups.
[F] Denotes that a Fisher's Exact test was used in the analysis of a 2x2 contingency table.

Table 4. Contingency table analysis of the relationship between vessel size and status for the southeast Florida region.

Factors	df	Likelihood Ratio X^2	P	Outcome
Size (< 10 m, 10 - 20 m, > 20 m) Status (Anchored, not anchored)	3,408	35.827	**<0.001**	
Size (< 10 m, 10 - 20 m) Status (Anchored, not anchored)	3,375	34.499[F]	**<0.001**	< 10 m > anchoring
Size (10 - 20 m, > 20 m) Status (Anchored, not anchored)	501	6.830[F]	**0.0072**	> 20 m > anchoring
Size (< 10 m, > 20 m) Status (Anchored, not anchored)	2,939	0.855[F]	0.3612	

P-values in **bold** represent a significant difference between treatment groups.
[F] Denotes that a Fisher's Exact test was used in the analysis of a 2x2 contingency table.

Use level was considered an independent variable in this analysis and had a significant effect on the dependent variables: class (Table 5), size (Table 6), activity (Table 7), and status (Table 8). In each case mini-season data were also removed to determine what affect these data had on the outcome.

There was no difference in the class of vessels observed on weekends and holidays ($p = 0.0852$) (Table 5). These use levels were then combined and compared to weekdays. In this analysis there were significantly more recreational vessels observed on weekends/holidays than weekdays ($p < 0.001$). When the mini-season data were removed the results remained unchanged ($p < 0.001$).

Table 5. Contingency table analysis of the relationship between the use level and vessel class for the southeast Florida region.

Factors[1]	df	Likelihood Ratio X^2	P	Outcome
Use (wky, wkd, hly) Class (Recreational, commercial)	3,396	59.673	**<0.001**	
Use (wkd, hly) Class (Recreational, commercial)	2,887	2.072[F]	0.0852	
Use (wky, wkd+hly) Class (Recreational, commercial)	3,396	57.601[F]	**<0.001**	wkd + hly > Rec
Use (wky, wkd, hly) – NO MINI Class (Recreational, commercial)	2,777	50.994	**<0.001**	
Use (wkd,hly) – NO MINI Class (Recreational, commercial)	2,268	0.761[F]	0.2143	
Use (wky, wkd+hly) – NO MINI Class (Recreational, commercial)	2,777	50.233	**<0.001**	wkd + hly > Rec

P-values in **bold** represent a significant difference between treatment groups.
[F] Denotes that a Fisher's Exact test was used in the analysis of a 2x2 contingency table.
[1] Abbreviations are weekday (wky), weekend (wkd), and holiday (hly). NO MINI means that the lobster mini-season survey was excluded from the analysis, otherwise it was included with holiday surveys.

Use level had a significant effect on the size of the vessels observed (p = 0.0136) (Table 6). Multiple comparisons revealed this difference to be due to greater numbers of vessels > 20 m in length observed on weekdays compared to vessels < 10 m (p = 0.0117) or 10 – 20 m (p = 0.0132), and more vessels > 20 m compared to < 10 m on weekends rather than holidays (p = 0.0250). When mini-season data were removed from the analysis, there was no significant difference (p = 0.1425).

Table 6. Contingency table analysis of the relationship between the survey use level and vessel size for the southeast Florida region.

Factors[1]	**df**	**Likelihood Ratio X^2**	**P**	**Outcome**
Use (wky, wkd, hly) Size (< 10 m, 10 - 20 m, > 20 m)	3,407	12.566	**0.0136**	
Use (wky, wkd, hly) Size (< 10 m, 10 - 20 m)	3,375	4.915	0.0856	
Use (wky, wkd, hly) Size (10 - 20 m, > 20 m)	501	6.392	**0.0409**	
Use (wky, wkd, hly) Size (< 10 m, > 20 m)	2,938	7.839	**0.0199**	
Use (wky, wkd) Size (< 10 m, > 20 m)	1,461	0.5210[F]	0.5044	
Use (wky, hly) Size (< 10 m, > 20 m)	1,925	6.132[F]	**0.0117**	wky > (> 20 m)
Use (wkd, hly) Size (< 10 m, > 20 m)	2,491	4.670[F]	**0.0250**	wkd > (> 20 m)
Use (wky, wkd) Size (< 10 m, 10 - 20 m, > 20 m)	1,710	3.176	0.2043	
Use (wky, wkd) Size (10 - 20 m, > 20 m)	273	1.488[F]	0.1542	
Use (wky, hly) Size (10 - 20 m, > 20 m)	300	5.966[F]	**0.0132**	wky > (> 20 m)
Use (wky, wkd, hly) – NO MINI Size (< 10 m, 10 - 20 m, > 20 m)	2,788	6.877	0.1425	

P-values in **bold** represent a significant difference between treatment groups.
[F] Denotes that a Fisher's Exact test was used in the analysis of a 2x2 contingency table.
[1] Abbreviations are weekday (wky), weekend (wkd), and holiday (hly). NO MINI means that the lobster mini-season survey was excluded from the analysis, otherwise it was included with holiday surveys.

Use level had a significant effect on the vessel activity observed ($p < 0.001$)(Table 7). Pair-wise comparisons revealed this difference to be due to more fishing on weekends than holidays ($p < 0.001$), and more fishing on weekdays than weekends ($p < 0.001$). When mini-season data were removed from the analysis, the effect of weekend versus holiday use periods on activity was not significantly different ($p = 0.1094$). As these results were not significantly different, weekend and holiday data were combined and compared to weekdays. This analysis once again revealed significantly more fishing activity on weekday than weekend/holiday ($p < 0.001$).

Table 7. Contingency table analysis of the relationship between the survey use level and vessel activity for the southeast Florida region.

Factors[1]	df	Likelihood Ratio X^2	P	Outcome
Use (wky, wkd, hly) Activity (Fish, Dive/snorkel)	3,211	283.326	**<0.001**	
Use (wkd, hly) Activity (Fish, Dive/snorkel)	2,718	119.609[F]	**<0.001**	wkd > fishing
Use (wky, wkd) Activity (Fish, Dive/snorkel)	1,583	50.297[F]	**<0.001**	wky > fishing
Use (wky, wkd, hly) – NO MINI Activity (Fish, Dive/snorkel)	2,613	52.281	**<0.001**	
Use (wkd, hly) – NO MINI Activity (Fish, Dive/snorkel)	2,120	1.634[F]	0.1094	
Use (wky, wkd+hly) – NO MINI Activity (Fish, Dive/snorkel)	2,613	50.647[F]	**<0.001**	wky > fishing

P-values in **bold** represent a significant difference between treatment groups.
[F] Denotes that a Fisher's Exact test was used in the analysis of a 2x2 contingency table.
[1] Abbreviations are weekday (wky), weekend (wkd), and holiday (hly). NO MINI means that the lobster mini-season survey was excluded from the analysis, otherwise it was included with holiday surveys.

Use level had a significant effect on the frequency of anchoring observed ($p < 0.001$)(Table 8). There was no significant difference in anchoring between weekend and holidays ($p = 0.3482$), so these data were combined and compared to the weekday data. There was significantly more anchoring on weekend/holiday compared to weekday ($p < 0.001$). When mini-season data were removed from the analysis the relationship between weekends and holidays became significant with more frequent anchoring on weekends ($p = 0.163$).

Table 8. Contingency table analysis of the relationship between the survey use level and vessel status for the southeast Florida region.

Factors[1]	df	Likelihood Ratio X^2	P	Outcome
Use (wky, wkd, hly) Status (Anchored, not anchored)	3,408	84.115	**<0.001**	
Use (wkd, hly) Status (Anchored, not anchored)	2,896	0.184[F]	0.3482	
Use (wky, wkd+hly) Status (Anchored, not anchored)	2,649	58.977[F]	**<0.001**	wkd + hly > anchoring
Use (wkd, hly) – NO MINI Status (Anchored, not anchored)	2,277	4.759[F]	**0.0163**	wkd > anchoring

P-values in **bold** represent a significant difference between treatment groups.

[F] Denotes that a Fisher's Exact test was used in the analysis of a 2x2 contingency table.

[1] Abbreviations are weekday (wky), weekend (wkd), and holiday (hly). NO MINI means that the lobster mini-season survey was excluded from the analysis, otherwise it was included with holiday surveys.

4.3 Describing and analyzing the spatial and temporal patterns of vessels

The purpose of the spatial analyses was to determine if the observed vessels were randomly distributed across the study area or if they exhibited statistically significant patterns of dispersion and/or clustering that were associated with particular benthic habitat types or activities.

The results from a spatial analysis are dependent on (sensitive to) the general configuration (e.g., shape and size) of the areal unit that contains the features for which the analysis is being conducted. For this project, the areal unit of analysis, as previously described, generally extended from the shoreline (west boundary) to the 35 m depth contour (east boundary). The distance between these two features varied significantly on the aerial observation route from the southern-most to the northern-most boundary of the study area.

4.3.1 Description of the spatial extent and configuration of the study area

The south to north extent of the study area is approximately 183 kilometers (km) (Fig. 31). The most southerly point is Fowey Rocks Light[4] and the most northerly is the border of Martin and St. Lucie counties. The south to north extent of the study area off Miami-Dade, Broward, Palm Beach, and Martin counties is 42 km, 38 km, 72 km, and 31 km, respectively. The size of the study area is 873 km^2, and the portions off Miami-Dade, Broward, Palm Beach, and Martin counties are 208 km^2, 109 km^2, 252 km^2, and 304 km^2, respectively.

The width of the study area, from west (nearshore) to east (offshore), ranges from about 1.4 km to 12.9 km. The area widens substantially in both the extreme south and the extreme north. In the south, the widest portion is about 8 km near the southern tip of Key Biscayne. In the north, the widest portion is about 13.9 km near St. Lucie Inlet. To minimize any confounding effects on the spatial analyses caused by variations in the study area configuration, the vessel patterns were analyzed by county.

4.3.2 Examining vessel distributions by flight date

An assumption of the spatial analysis was that the vessels observed and recorded during each flight were members of the same underlying population. To test this assumption, the state plane coordinates describing the west-to-east locations (e.g., longitudes) of the observed vessels were used to compare and analyze spatial patterns exhibited during each flight. The number of vessels logged during each flight ranged from 140 on 07/2/2008 to 619 on 07/30/2008, which

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[4] Fowey Rocks Light, a radar transponder beacon, is located at 25°35'24"N., 80°05'48"W.

occurred during the lobster mini-season (Fig. 32). A total of 3,406 vessels were logged across all flights. Inclement weather forced the abortion of the 9th flight on 09/19/09 before the entire study area had been surveyed; the area that remained was surveyed on 10/03/09.

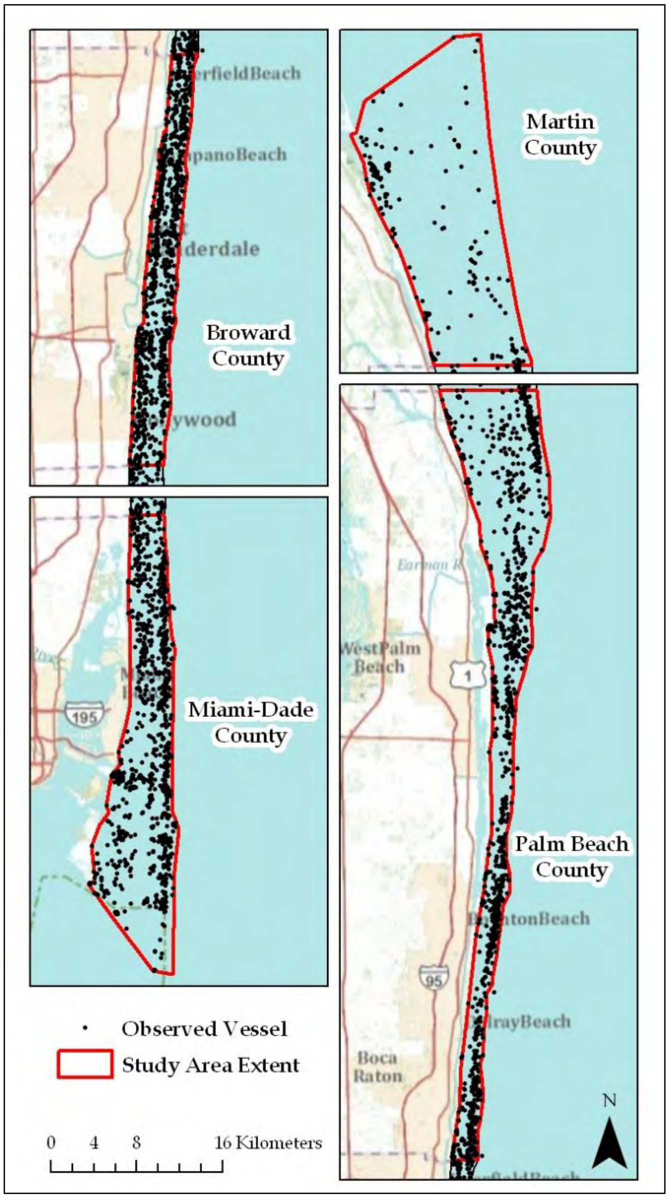

Figure 31. Shape, size, and boundaries of the study area off Miami-Dade, Broward, Palm Beach, and Martin counties.

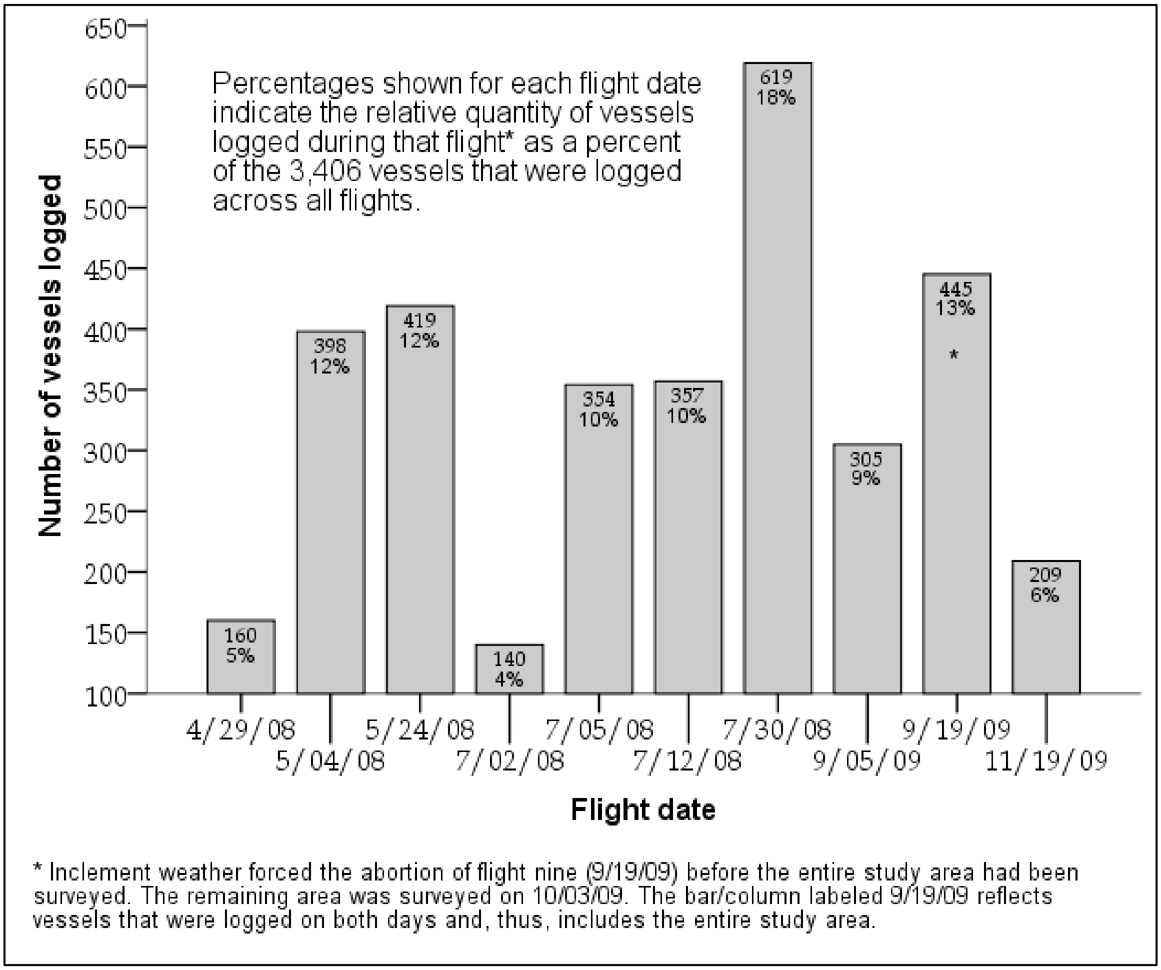

Figure 32. Number of vessels observed during each flight.

Three flights were on a weekday, three on a weekend, and three were on a holiday (Fig. 33). The 07/30/08 flight during the lobster mini-season is not included on Figure 33 since this was a special event. On average, 170 vessels were observed on a weekday flight, 400 on a weekend flight, and 359 on a holiday flight.

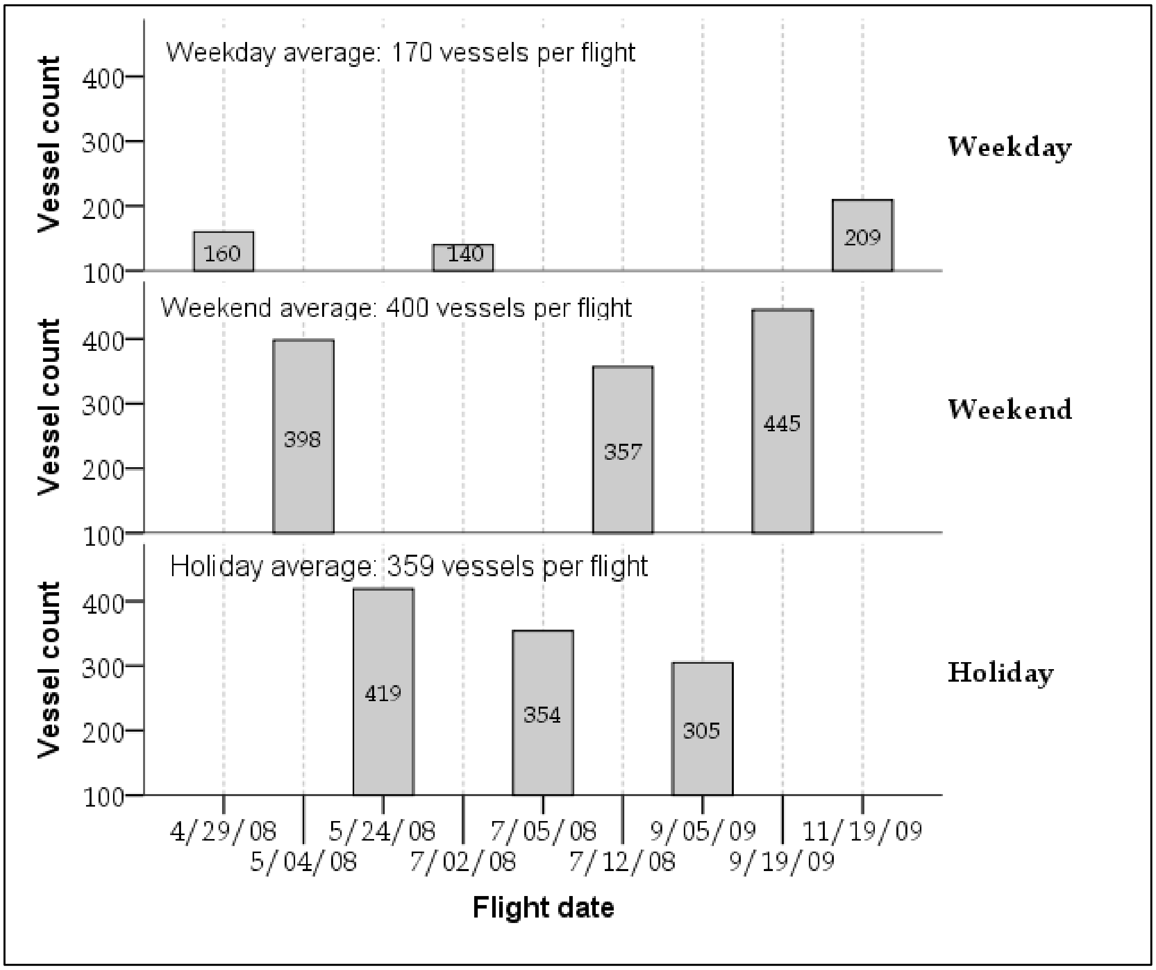

Figure 33. Number of vessels observed on weekday, weekend, and holiday flights.

The total number of vessels recorded during all 10 flights was 976 off Miami-Dade County, 1,091 off Broward County, 1,162 off Palm Beach County, and 177 off Martin County (Fig. 34).

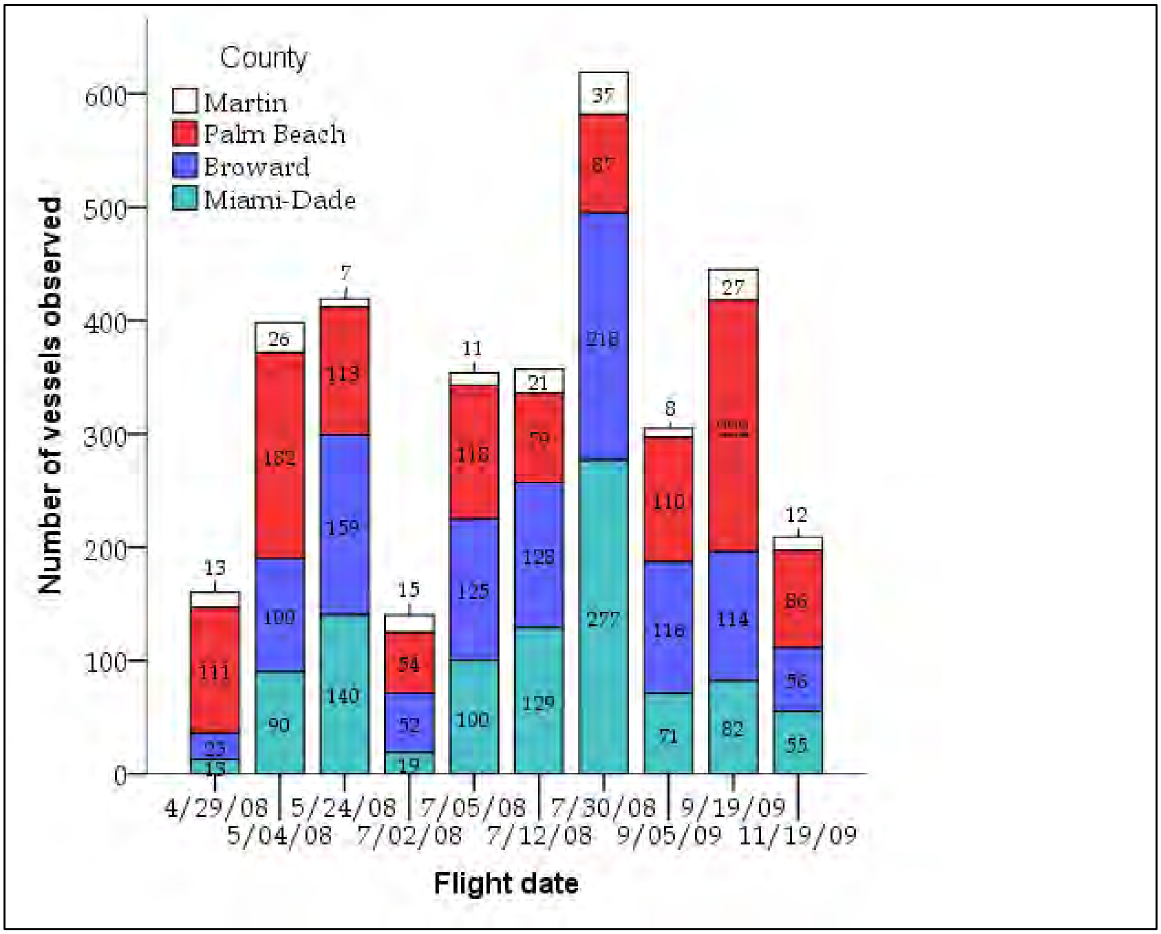

Figure 34. Number of vessels observed by flight and by county.

The Directional Distribution tool in ArcGIS® 10.0 (ESRI 2010) was used to create, for each county, an ellipse of one standard deviation (SD) representing the vessels observed during the lobster mini-season flight, and a 1 SD ellipse representing all vessels observed during the other nine flights combined. The two ellipses were used to summarize and compare the spatial charactersistics and distributions of the vessels observed during the mini-season flight with those observed during the other nine flights combined.

When the underlying spatial pattern of vessels is a spatially normal distribution, an ellipse of one standard deviation will cover approximately 68% of all the vessels from which it is created. The ellipse of 1 SD generated from the 277 vessels observed off Miami-Dade County during the lobster mini-season flight covered 62% (172) of these vessels (Fig. 35). The 1 SD ellipse generated from the 699 vessels observed during the remaining nine flights covered 65% (454) of these vessels. In contrast, the mini-season ellipse covered only 15% (103) of the 699 vessels observed during the nine flights, while the ellipse created from the nine flights covered 34% (93) of the vessels observed during the mini-season flight.

Figure 35. Standard Deviational Ellipses showing directional trends for vessels off Miami-Dade County (1 standard deviation).

The mean center of the distribution of mini-season vessels observed off Miami-Dade County was 2.2 km west and 1.5 km north of the distribution of vessels for the other nine flights (Fig. 35, 36). Parametric and non-parametric tests were conducted at a significance level of .05 to determine whether the distribution (in the east-west direction) of vessels observed off Miami-Dade County during the lobster mini-season was the same as (null hypothesis) or different from (alternate hypothesis) the distribution of vessels observed during the remaining flights. A one-way ANOVA was significant, $F(1, 974) = 442.7$, $p < 0.001$, as was an Independent-Samples Mann-Whitney U test ($p < 0.001$). These results led to rejection of the null hypothesis and acceptance of the alternate: the west-to-east distribution of lobster mini-season vessels off Miami-Dade County was different from that of vessels observed during the other nine flights. In other words, in general the vessels recorded off Miami-Dade County during the lobster mini-season were closer to shore (in shallower waters) than were the vessels observed during all other flights.

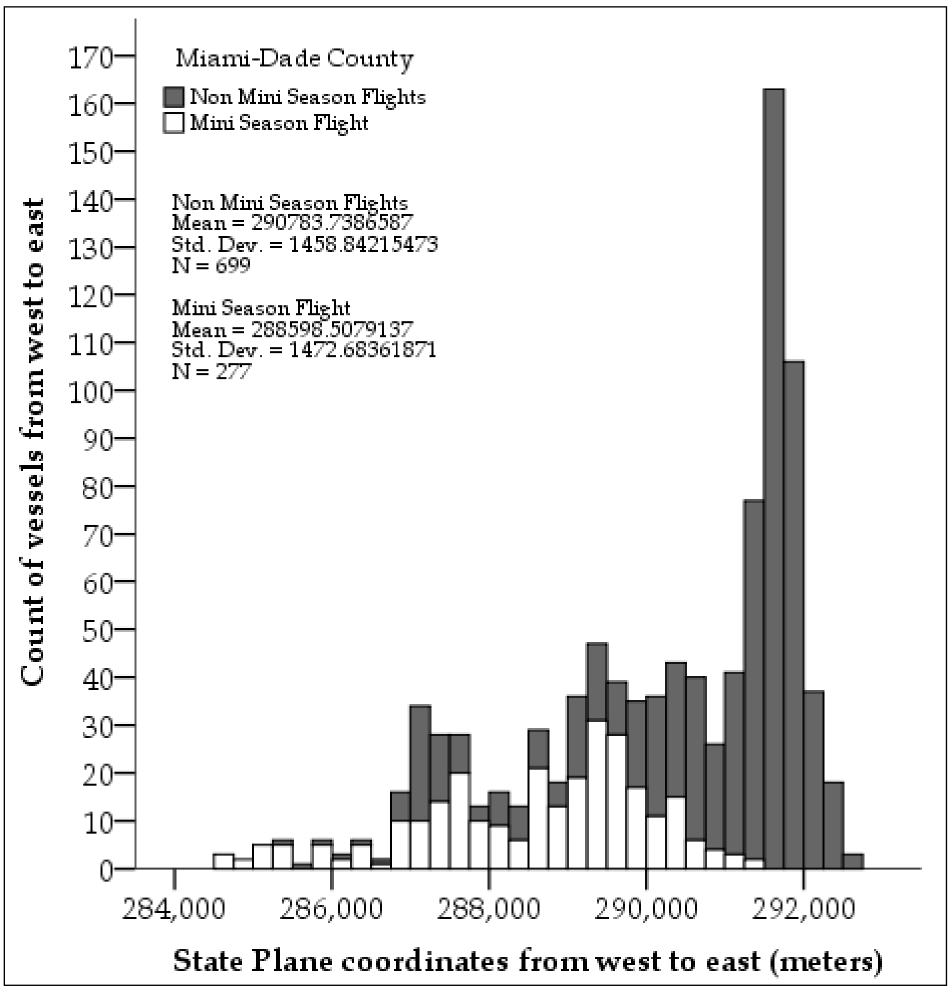

Figure 36. West-to-east distribution of vessels observed off Miami-Dade County during the lobster mini-season flight versus those observed during all other flights.

The 1 SD ellipse generated from the 218 vessels observed off Broward County during the lobster mini-season flight covered 61% (134) of these vessels (Fig. 37). The 1 SD ellipse generated from the 873 vessels observed during the remaining nine flights covered 60% (524) of these vessels. In contrast, the mini-season ellipse covered 40% (348) of the 873 vessels observed during the nine flights, while the ellipse created from the nine flights covered 38% (82) of the vessels observed during the mini-season flight. The mean center of the distribution of mini-season vessels observed off Broward County was 1.1 km west and 4.7 km south of the distribution of the nine flights (Fig. 37, 38).

A one-way ANOVA was significant, $F(1, 1{,}089) = 149.3$, $p < 0.001$, as was an Independent-Samples Mann-Whitney U test ($p < 0.001$). These results led to rejection of the null hypothesis and acceptance of the alternate: the west-to-east distribution of lobster mini-season vessels off Broward County was different from that of all other vessels. In other words, in general the vessels recorded during the lobster mini-season off Broward County were closer to shore (in shallower waters) than were the vessels observed during all other flights.

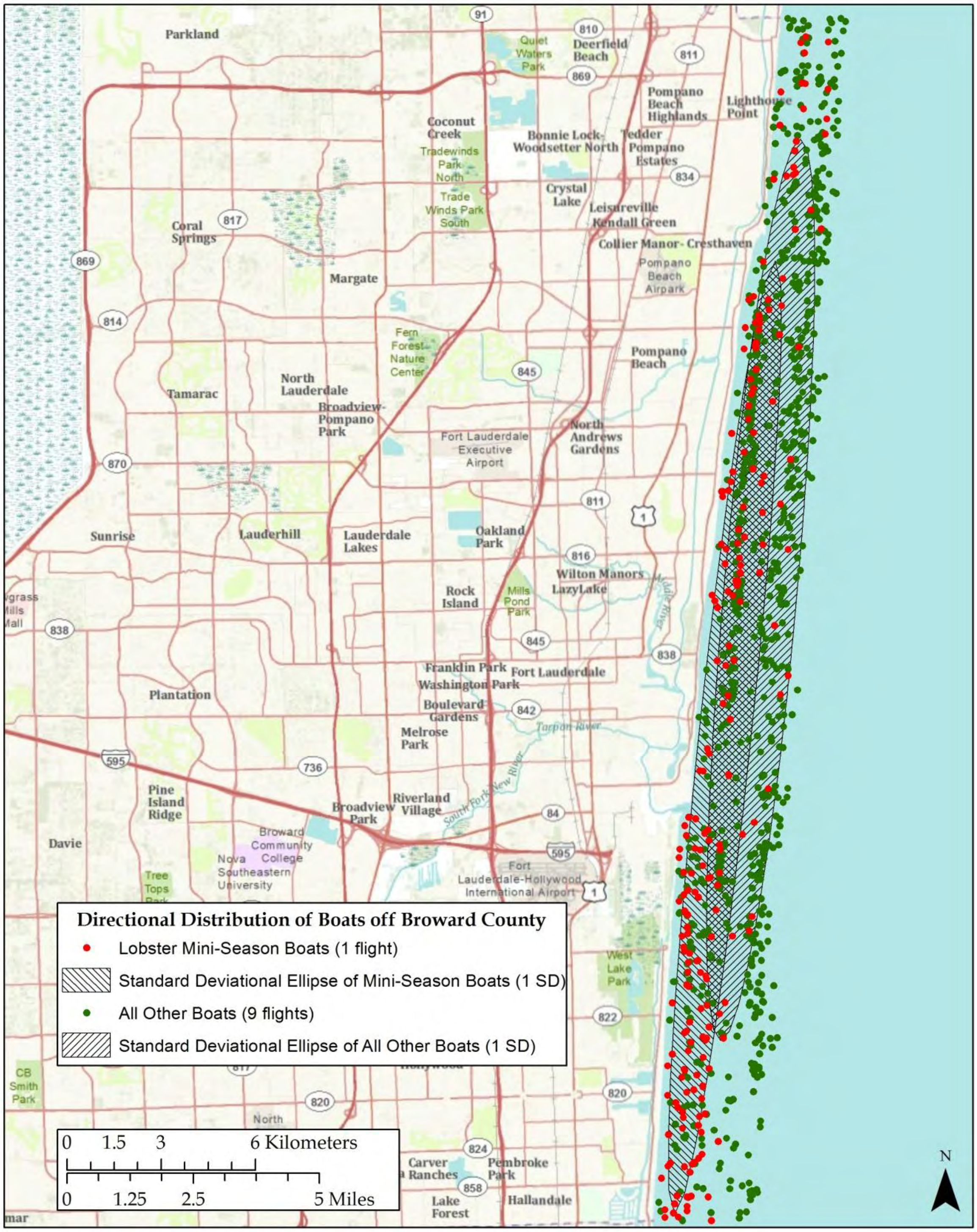

Figure 37. Standard Deviational Ellipses showing directional trends for vessels off Broward County (1 standard deviation).

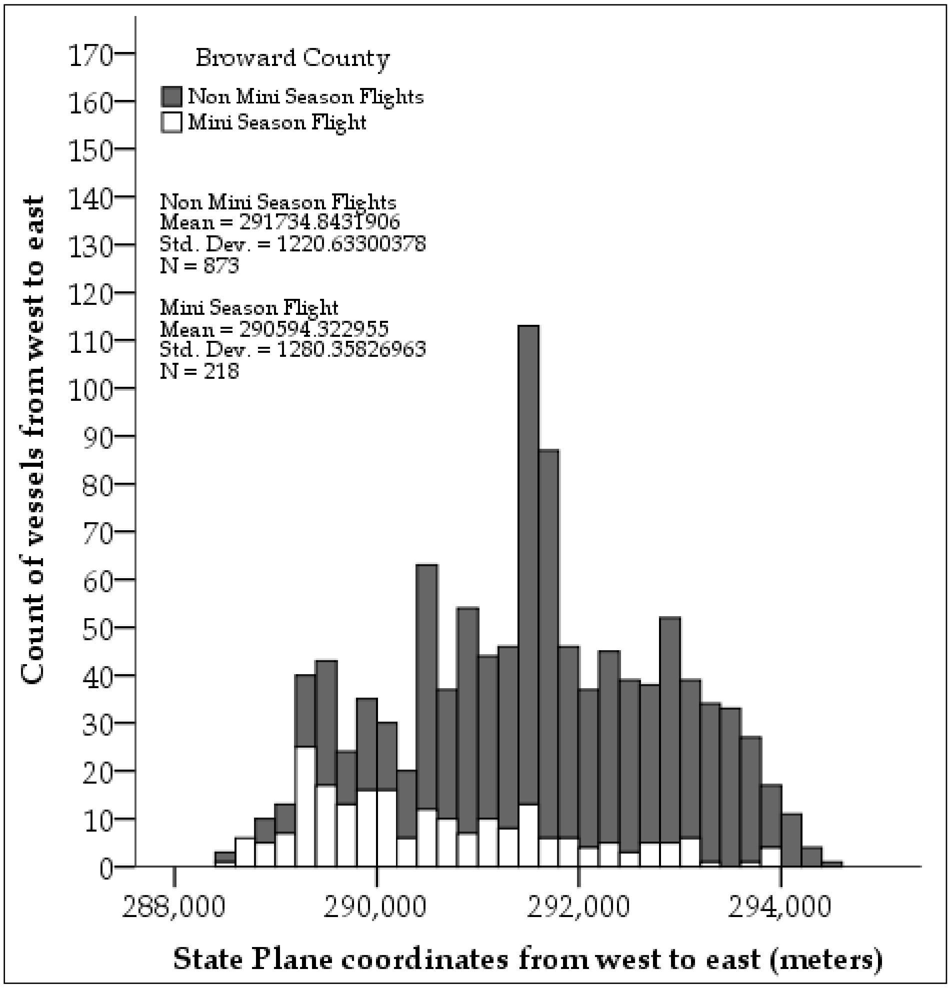

Figure 38. West-to-east distribution of vessels observed off Broward County during the lobster mini-season flight versus those observed during all other flights.

The 1 SD ellipse generated from the 87 vessels observed off Palm Beach County during the lobster mini-season flight covered 64% (56) of these vessels (Fig. 39). The 1 SD ellipse generated from the 1,075 vessels observed during the remaining nine flights covered 66% (707) of these vessels. In contrast, the mini-season ellipse covered 61% (654) of the 1,075 vessels observed during the nine flights, while the ellipse created from the nine flights covered 67% (58) of the vessels observed during the mini-season flight. The mean center of the distribution of mini-season vessels observed off Palm Beach County was 0.4 km west and 4.9 km north of the distribution of the nine flights (Fig. 39).

The results of parametric and non-parametric tests conducted for Palm Beach County were insufficient to reject the null hypothesis. The one-way ANOVA was not significant, $F(1, 1{,}160) = 3.297$, $p = 0.070$, nor was an Independent-Samples Mann-Whitney U test ($p < 0.103$). These results led to the conclusion that differences could not be detected between the west-to-east distribution of vessels observed off Palm Beach County during the lobster mini-season and the distribution of vessels observed during all other flights.

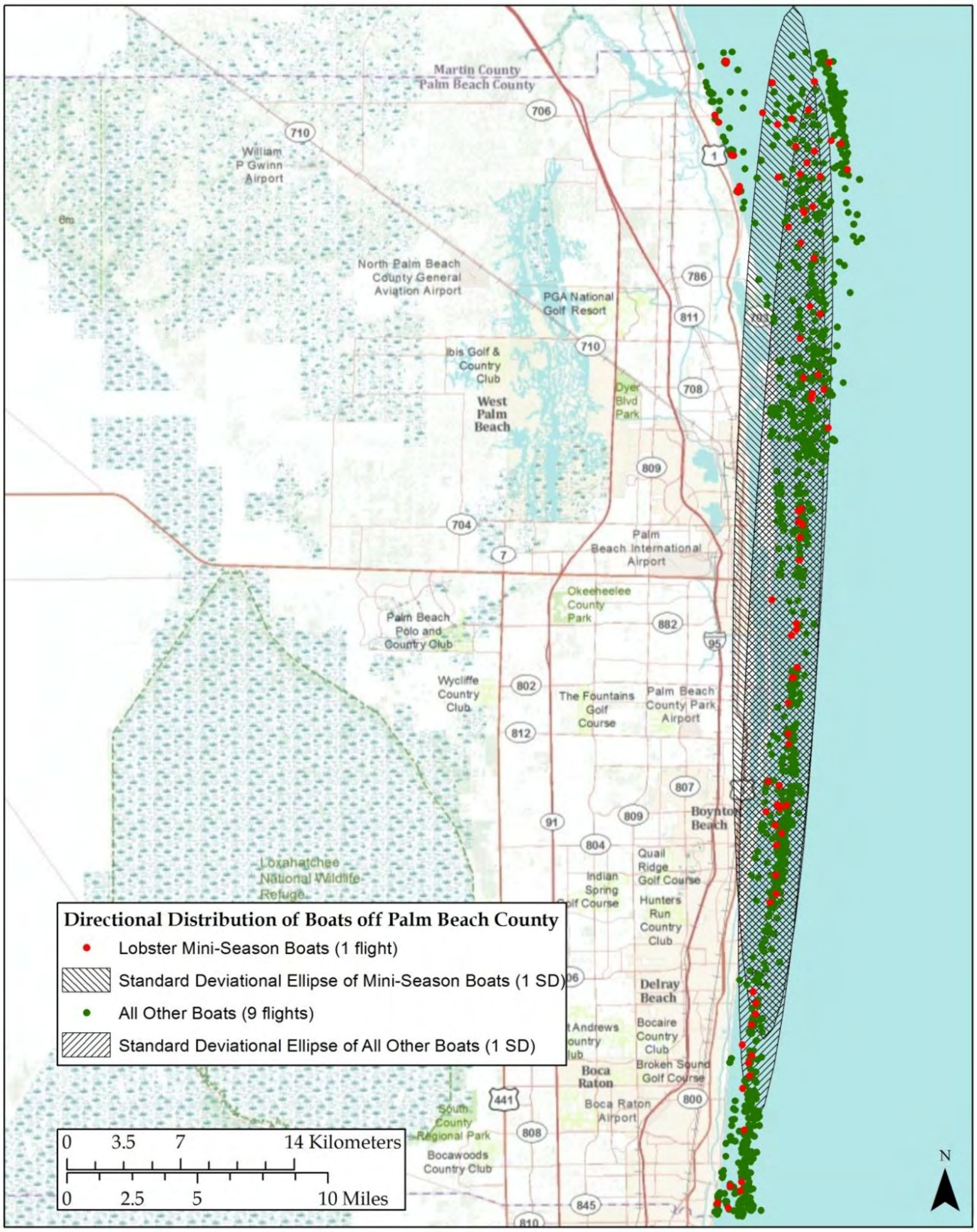

Figure 39. Standard Deviational Ellipses showing directional trends for vessels off Palm Beach County (1 standard deviation).

The 1 SD ellipse generated from the 37 vessels observed off Martin County during the lobster mini-season flight covered 84% (31) of the vessels (Fig. 40). The 1 SD ellipse generated from the 140 vessels observed during the remaining nine flights covered 63% (88) of the vessels. In contrast, the mini-season ellipse covered only 24% (34) of the 140 vessesls observed during the nine flights, while the ellipse created from the nine flights covered 81% (30) of the vessels observed during the mini-season flight. The mean center of the distribution of mini-season vessels observed off Martin County was 5.0 km west and 3.6 km north of the distribution of the nine flights (Fig. 40, 41).

A one-way ANOVA was significant, $F(1, 175) = 40.058$, $p < 0.001$, as was an Independent-Samples Mann-Whitney U test ($p < 0.001$). These results led to rejection of the null hypothesis and acceptance of the alternate: the west-to-east distribution of lobster mini-season vessels off Martin County was different from that of all other vessels. In other words, in general the vessels recorded during the lobster mini-season off Martin County were closer to shore (in shallower waters) than were the vessels observed during all other flights.

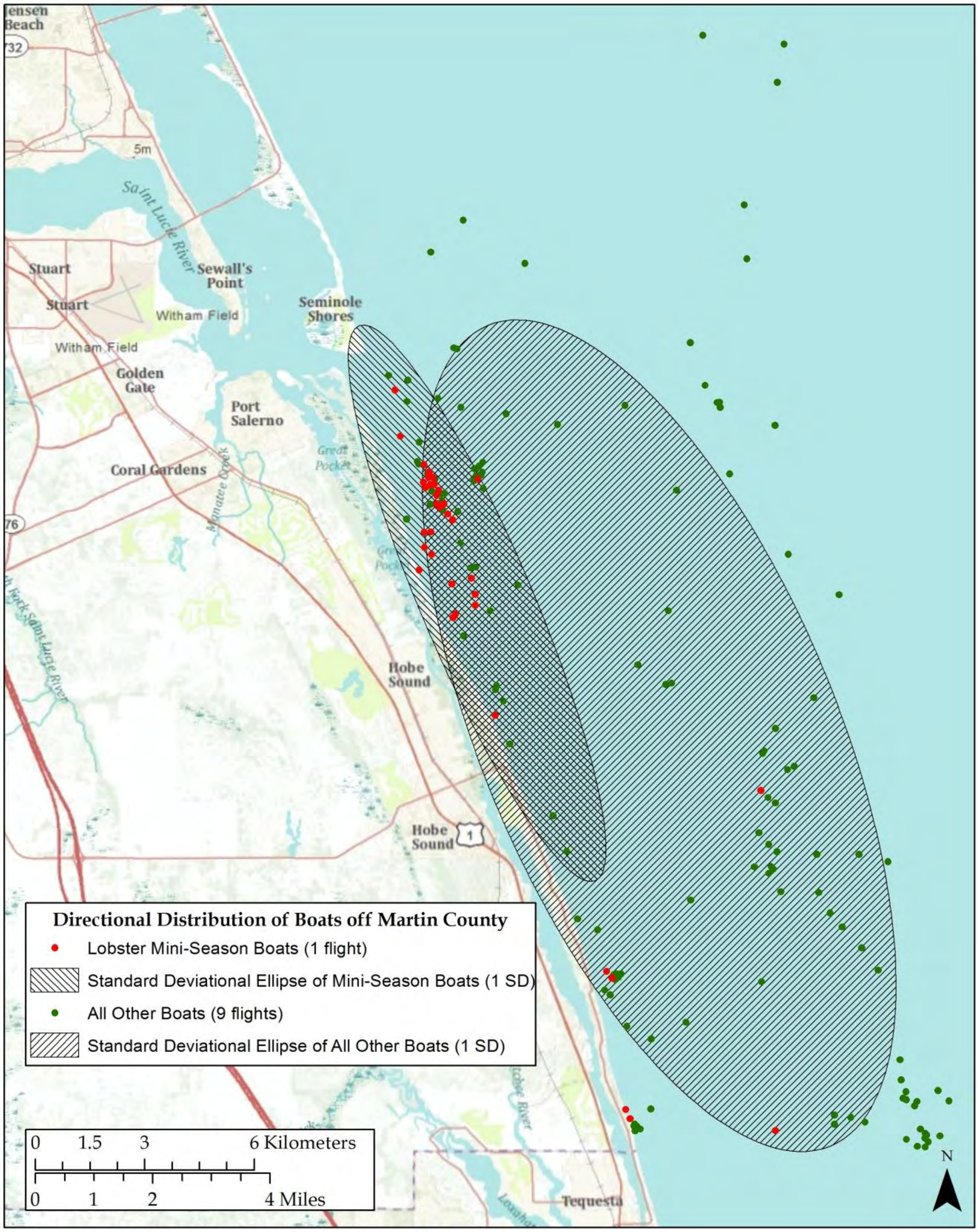

Figure 40. Standard Deviational Ellipses showing directional trends for vessels off Martin County (1 standard deviation).

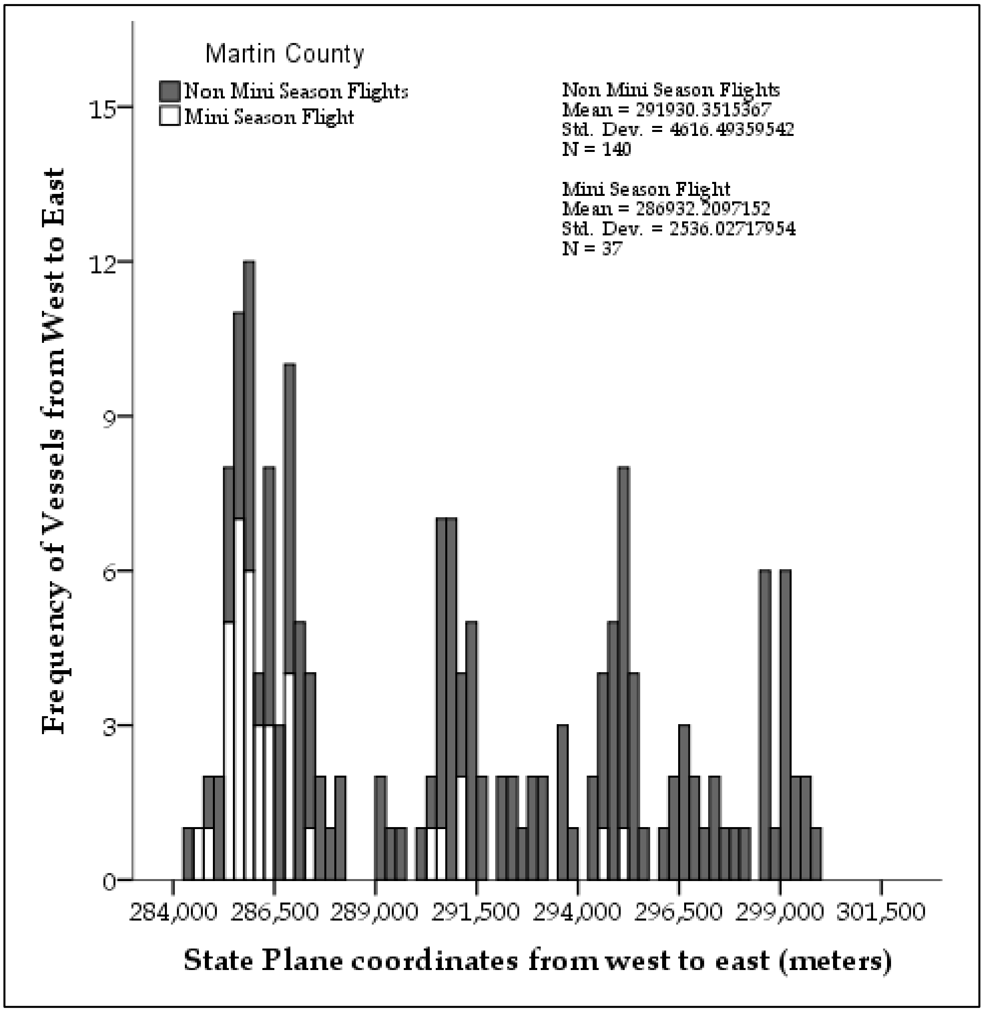

Figure 41. West-to-east distribution of vessels observed off Martin County during the lobster mini-season flight versus those observed during all other flights.

4.3.3 Cluster analysis of vessels

The next task was to determine if the observed vessels were randomly distributed across the study area or if, instead, they exhibited statistically significant patterns of dispersion and/or clustering. To do so, Getis-Ord Gi* statistics were calculated for each vessel observed during nine flights. The mini-season flight was excluded since it represented a special event and because, as previously shown, the spatial distribution of vessels on that day exhibited different characteristics than that of the other nine flights combined. The 189 moored vessels also were excluded from the analysis, since they occurred at fixed locations.

The Z score that results from a Getis-Ord Gi* analysis is indicative of where vessels with either high or low values cluster spatially (ESRI 2010). The analysis examined each vessel within the context of neighboring vessels, and a statistically significant hot spot comprised features that had high values. The value used to conduct the hot spot analysis was the number of neighboring vessels that were within set distances of each observed vessel. The local sum for a vessel and its neighbors was compared proportionally to the sum for all vessels; when the local sum was much different from the expected local sum, and that difference was too large to be the result of random chance, a statistically significant Z score resulted. A number of steps were necessary to generate the input values for the Getis-Ord Gi* analysis.

The first step was to conduct a point distance analysis. For each vessel, the number of neighboring vessels within a set radial distance was counted and that value was assigned to the vessel being examined. The point distance analysis was repeated using a series of radial distances that were determined via the ArcGIS® Multi-Distance Spatial Cluster Analysis tool, which is based on Ripley's K-Function (Mitchell 2005). This tool summarizes spatial dependence (feature clustering or feature dispersion) over a range of distances (ESRI 2010). Input to the tool consisted of a starting distance from the vessel under evaluation, a distance increment in meters, and the number of sequential distances to evaluate. The tool computed the average number of neighboring vessels associated with each vessel; neighboring vessels were those closer than the distance being evaluated. If the average number of vessels for a particular evaluation distance was more than the average concentration of vessels throughout the study area, the distribution was considered clustered at that distance.

Patterns of spatial clustering and dispersion of vessels off each county were determined for four distances. The range of distances at which clustering and dispersion occurred varied due to the nature of the study area: narrower off Broward and Palm Beach counties than off Miami-Dade and Martin counties. In general, clustering occurred at shorter distances for the narrower (more compact) portions of the study area than for wider areas.

The distances for Miami-Dade and Martin counties were 400 m, 600 m, 800 m, and 1000 m (Fig. 42, 45), and those for Broward and Palm Beach counties were 200 m, 400 m, 600 m, and 800 m (Fig. 43, 44). The color-coding of the vessels indicates areas of significant dispersion (blue; Z-score < -1.96), significant clustering (red; Z-score > 1.96), or neither dispersion or clustering (gray; Z-score between -1.96 and 1.96).

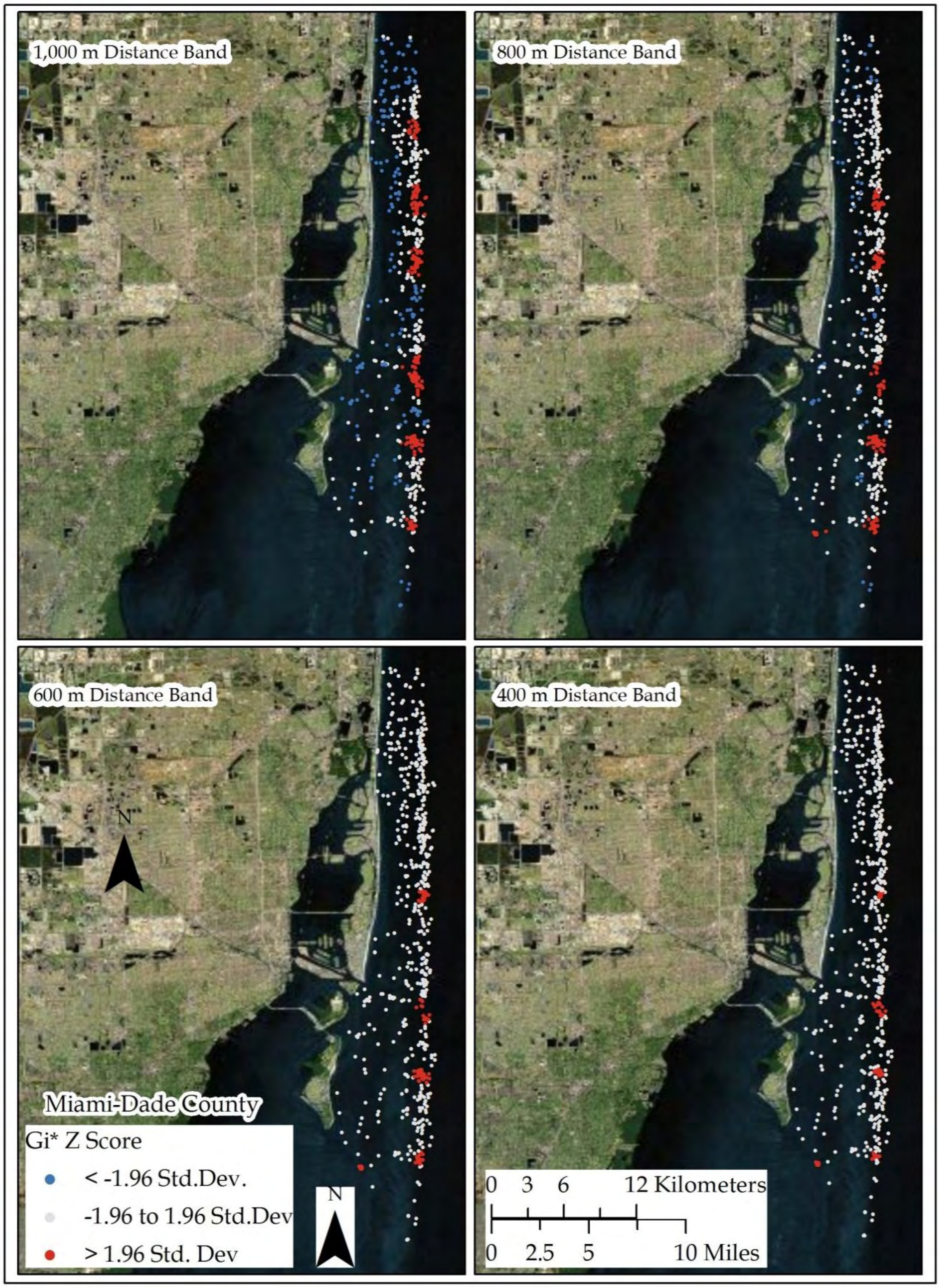

Figure 42. Patterns of spatial clustering of vessels off Miami-Dade County.

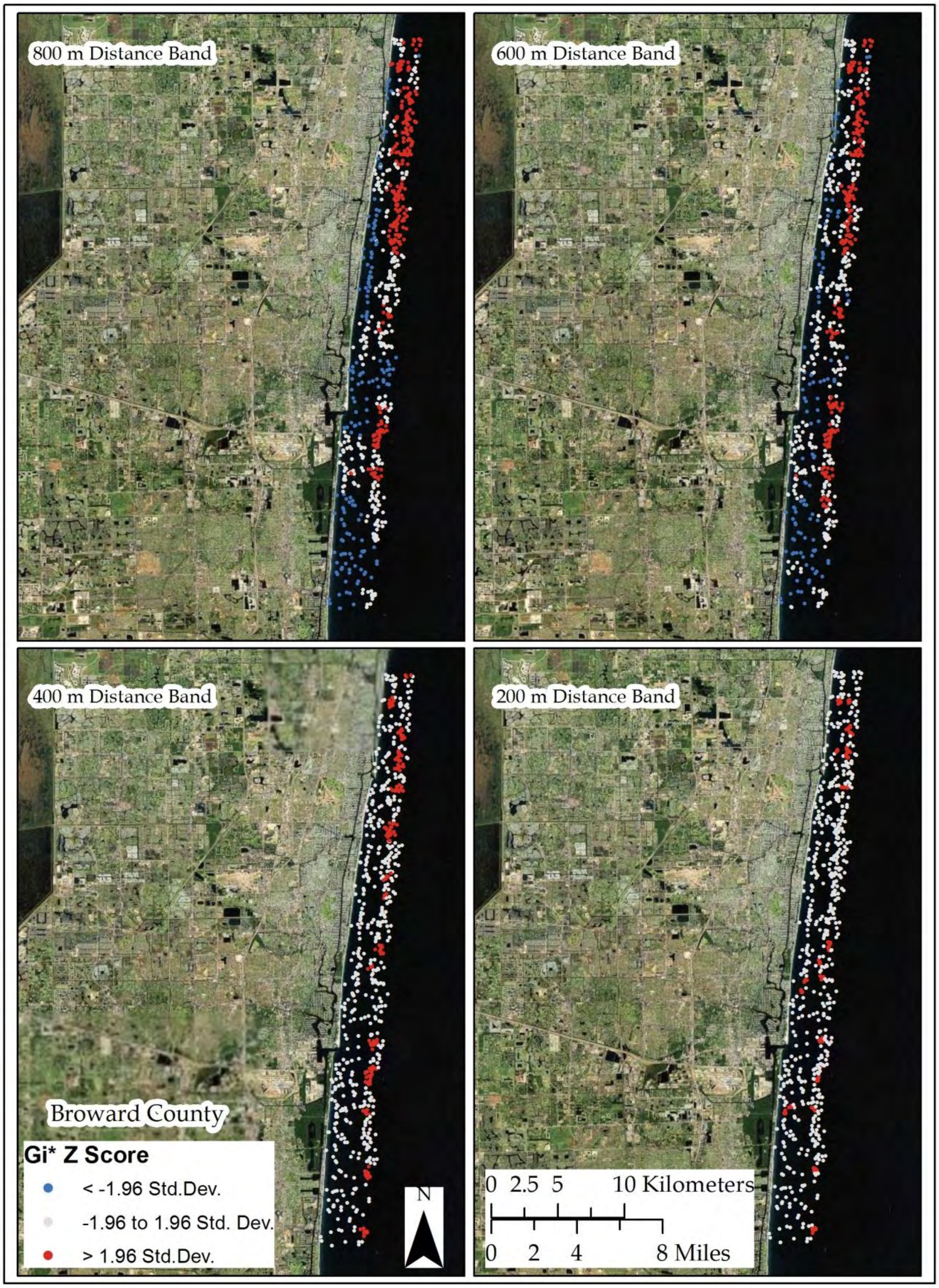

Figure 43. Patterns of spatial clustering of vessels off Broward County.

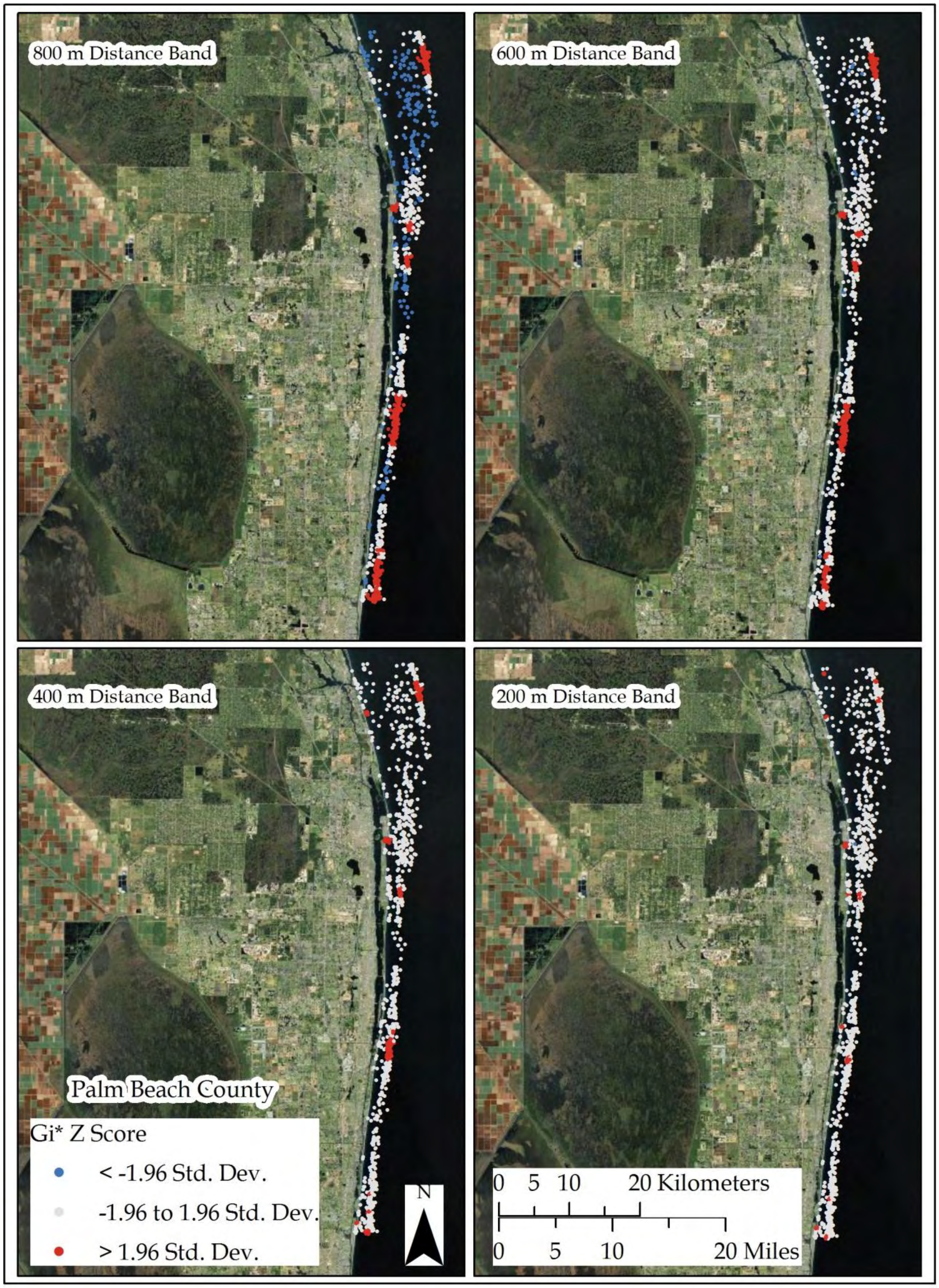

Figure 44. Patterns of spatial clustering of vessels off Palm Beach County.

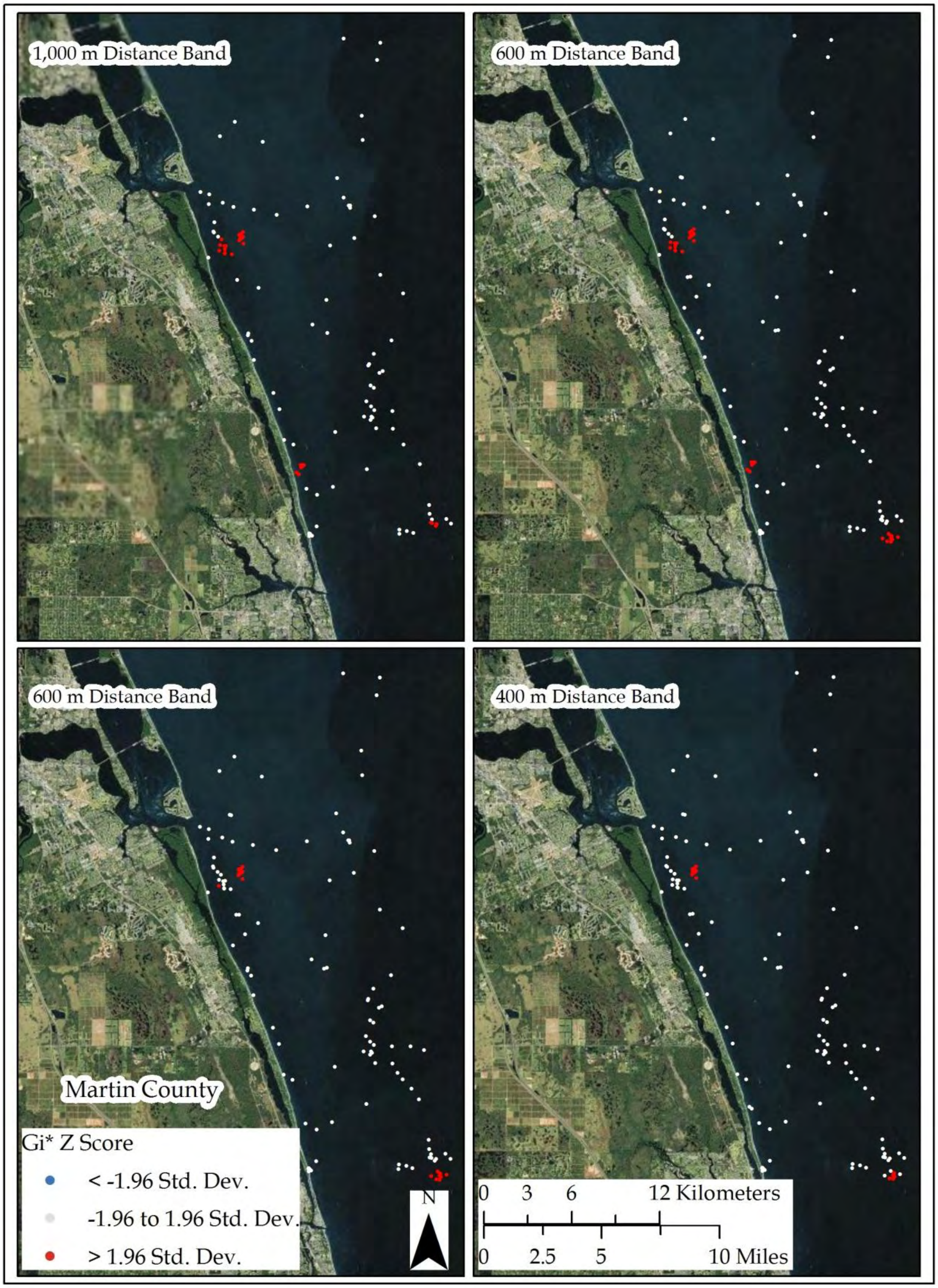

Figure 45. Patterns of spatial clustering of vessels off Martin County.

4.3.4 Associations of vessels and benthic habitat types

The area of benthic habitat that had been mapped for the 873 km^2 study area amounted to 565 km^2. Ninety-four percent (290 km^2) of the unmapped area was in Martin County and the remaining areas, totaling about 18 km^2, were located adjacent to the eastern-most boundary of the study area. These consisted of areas where vessels had been logged but habitat had not been mapped; these vessels were not included in the analysis of vessel to habitat associations.

The habitat types were grouped for mapping and analysis purposes. The groups were based on the classification scheme used by the authors of the GIS benthic habitat maps that were used for this study (Riegl et al. 2005, page 43). Six groups were created: Artificial, Hard-bottom, Reef, Sand, Seagrass, and Unknown. The constituents of the classification scheme that contributed to each group are listed below (note: only those types present in the study area are listed):

1. Artificial consists of artificial[5], inlet channels, and sand borrow areas.
2. Hard-bottom consists of colonized pavement, ridge, and scattered coral/rock in sand.
3. Reef consists of aggregated patch reef, linear reef, patch reef, and spur and groove.
4. Sand consists of sand (both deep and shallow).
5. Seagrass consists of seagrass (both continuous and discontinuous).
6. Unknown consists of areas that had been mapped but not typed.

Sand comprised over half of the mapped habitat (300 km^2), ranging from 45.1% of habitat off Broward County to 60.9% of habitat off Palm Beach County (Figure 46). Mapped hard-bottom (166 km^2) was the next most common habitat, ranging from 25.1% of habitat off Miami-Dade County to 33.3% of habitat off Palm Beach County. Reef comprised 10.5% of the study area (59 km^2), ranging from 0.3% of habitat off Martin County to 24.2% of that mapped off Broward County. The entire 21.29 km^2 of mapped seagrass was located off Miami-Dade County. The remaining 3.3% of the mapped area was in artificial (16 km^2), ranging from 1.4% of habitat off Palm Beach County to 5.9% off Martin County, and in unknown, the majority of which was off Martin County.

[5] Artificial includes man-made habitats such as submerged wrecks, large piers, submerged portions of rip-rap jetties, and the shoreline of islands created from dredge spoil (Riegl et al., 2005).

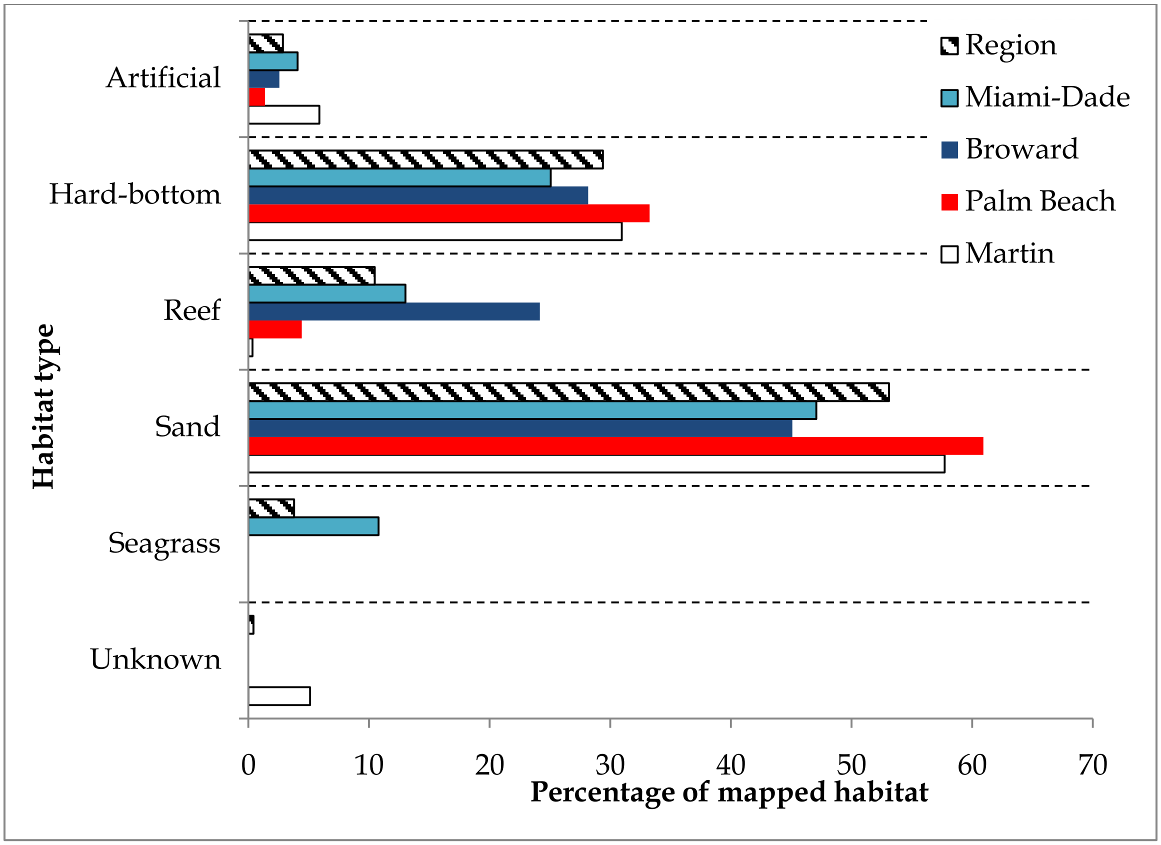

Figure 46. Percentage of habitat type in each county and the region.

A Location Quotient (LQ) statistic was used to measure the relative concentration of all vessels that were observed over each benthic habitat type. Moored vessels were not included since their location is pre-determined by the placement of moorings. The Location Quotient (LQ) is a ratio of proportions used to measure the concentration of a given group or activity in a specific geographic area relative to the concentration of the same group or activity within the larger study region to which the specific geographic area belongs (Mayer and Pleeter 1975; Wheeler et al. 1998). For the purposes of this analysis, the ratio used was the percentage of vessels that were observed over each habitat type divided by the percentage of total area that each habitat type represented. LQ ratios are interpreted as follows:

a) Ratio > 1.0: more vessels were observed over the habitat type than would be expected given the relative areal extent of the habitat as compared with the region as a whole.

b) Ratio = 1.0: the number of vessels observed was as would be expected given the relative areal extent of the habitat as compared with the region as a whole.

c) Ratio < 1.0: the number of vessels observed was less than would be expected given the relative areal extent of the habitat as compared with the region as a whole.

There were 2,296 vessels observed over habitat and 791 of them were anchored. Habitat types where the LQ for anchored vessels was less than 1, indicating fewer vessels than expected, included seagrass (0.20), sand (0.77), and hard-bottom (0.87) (Table 9). Habitat types where the LQ was greater than 1, indicating more anchored vessels than expected, included artificial (2.22) and reef (2.51). When considering all vessels, habitat types where the LQ was less than 1 included seagrass, unknown, sand, and hard-bottom, and habitat types where the LQ was greater than 1 included artificial and reef. The locations of anchored vessels in relation to mapped habitat are shown in Appendix 8.3.

Table 9. Location quotient analysis: the ratio of vessels to habitat area for the study area.

Habitat Type	Area		Anchored Vessels			All Vessels		
	Km^2	%	Count	%	Ratio	Count	%	Ratio
Artificial	16.11	2.85	50	6.32	2.22	89	3.88	1.36
Hard-bottom	166.06	29.39	202	25.54	0.87	623	27.13	0.92
Reef	59.20	10.48	208	26.30	2.51	514	22.39	2.14
Sand	300.07	53.10	325	41.09	0.77	1,061	46.21	0.87
Seagrass	21.29	3.77	6	0.76	0.20	8	0.35	0.09
Unknown	2.36	0.42	0	0.00	0.00	1	0.04	0.10
Totals	565.09	100.00	791	100.00	1.00	2,296	100.00	1.00

Off Miami-Dade County, there were 666 vessels observed over habitat and 363 of them were anchored (Table 10). Habitat types where the LQ for anchored vessels was less than 1, indicating fewer vessels than expected, included seagrass (0.15), hard-bottom (0.80), and sand (0.88) (Table 10). Habitat types where the LQ was greater than 1, indicating more anchored vessels than expected, included reef (1.99) and artificial (2.64). When considering all vessels, habitat types where the LQ was less than 1 included seagrass and hard-bottom, and habitat types where the LQ was greater than 1 included sand, reef, and artificial.

Table 10. Location quotient analysis: the ratio of vessels to habitat area for Miami-Dade County.

Habitat Type	Area		Anchored Vessels			All Vessels		
	Km^2	%	Count	%	Ratio	Count	%	Ratio
Artificial	8.04	4.07	39	10.74	2.64	51	7.66	1.88
Hard-bottom	49.50	25.05	73	20.11	0.80	122	18.32	0.73
Reef	25.72	13.02	94	25.90	1.99	141	21.17	1.63
Sand	93.02	47.08	151	41.60	0.88	344	51.65	1.10
Seagrass	21.29	10.78	6	1.65	0.15	8	1.20	0.11
Totals	197.57	100.00	363	100.00	1.00	666	100.00	1.00

Off Broward County, there were 634 vessels observed over habitat and 216 of them were anchored (Table 11). Habitat types where the LQ for anchored vessels was less than 1, indicating fewer vessels than expected, included sand (0.57) and artificial (0.72). Habitat types where the LQ was greater than 1, indicating more anchored vessels than expected, included hard-bottom (1.36) and reef (1.40). When considering all vessels, habitat types where the LQ was less than 1 included sand, artificial, and hard-bottom; reef was the only habitat type where the LQ was greater than 1.

Table 11. Location quotient analysis: the ratio of vessels to habitat area for Broward County.

Habitat Type	Area		Anchored Vessels			All Vessels		
	Km^2	%	Count	%	Ratio	Count	%	Ratio
Artificial	2.46	2.56	4	1.85	0.72	14	2.21	0.86
Hard-bottom	27.09	28.17	83	38.43	1.36	172	27.13	0.96
Reef	23.24	24.17	73	33.80	1.40	226	35.65	1.47
Sand	43.38	45.10	56	25.93	0.57	222	35.02	0.78
Totals	96.17	100.00	216	100.00	1.00	634	100.00	1.00

Off Palm Beach County, there were 943 vessels observed over habitat and 192 of them were anchored (Table 12). Habitat types where the LQ for anchored vessels was less than 1, indicating fewer vessels than expected, included unknown (0.00), hard-bottom (0.45), and sand (0.98). Habitat types where the LQ was greater than 1, indicating more anchored vessels than expected, included artificial (2.66) and reef (4.84). When considering all vessels, habitat types where the LQ was less than 1 included sand and hard-bottom, and habitat types were the LQ was greater than 1 included artificial, reef, and unknown.

Table 12. Location quotient analysis: the ratio of vessels to habitat area for Palm Beach County.

Habitat Type	Area		Anchored Vessels			All Vessels		
	Km²	%	Count	%	Ratio	Count	%	Ratio
Artificial	3.13	1.37	7	3.65	2.66	20	2.12	1.55
Hard-bottom	76.08	33.27	29	15.10	0.45	295	31.28	0.94
Reef	10.09	4.41	41	21.35	4.84	147	15.59	3.53
Sand	139.32	60.92	115	59.90	0.98	480	50.90	0.84
Unknown	0.07	0.03	0	0.00	0.00	1	0.11	3.59
Totals	228.69	100.00	192	100.00	1.00	943	100.00	1.00

Off Martin County, there were only 53 vessels observed over habitat and 20 of them were anchored. Given the low number of vessels that were observed (and the minimal amount of habitat that had been mapped to date), a location quotient analysis would not result in reliable results and, thus, it was not done.

A visual comparison between Miami-Dade, Broward, and Palm Beach counties shows that the largest location quotients (that were greater than 1) in each county were for anchored vessels on reef habitat or on artificial habitat (Figure 47). The location quotients for vesels on reef habitat were largest in Palm Beach (4.84) and Broward (1.40) counties, and the largest location quotient in Miami-Dade County was for vessels on artificial habitat (2.64). The second largest location quotients (greater than 1) for vessels on habitat in each county were for artificial habitat in Palm Beach County (2.66), hard-bottom in Broward County (1.36), and reef habitat in Miami-Dade (1.99). The remaining LQs for anchored vessels on mapped habitat in Miami-Dade (seagrass, hard-bottom, and sand), Broward (artificial and sand), and Palm Beach (sand and hard-bottom) counties were less than 1 (Figure 47). Note that there was mapped habitat in Palm Beach County that was classified as unknown; however, since no anchored vessels were observed on this habitat the location quotient equals zero.

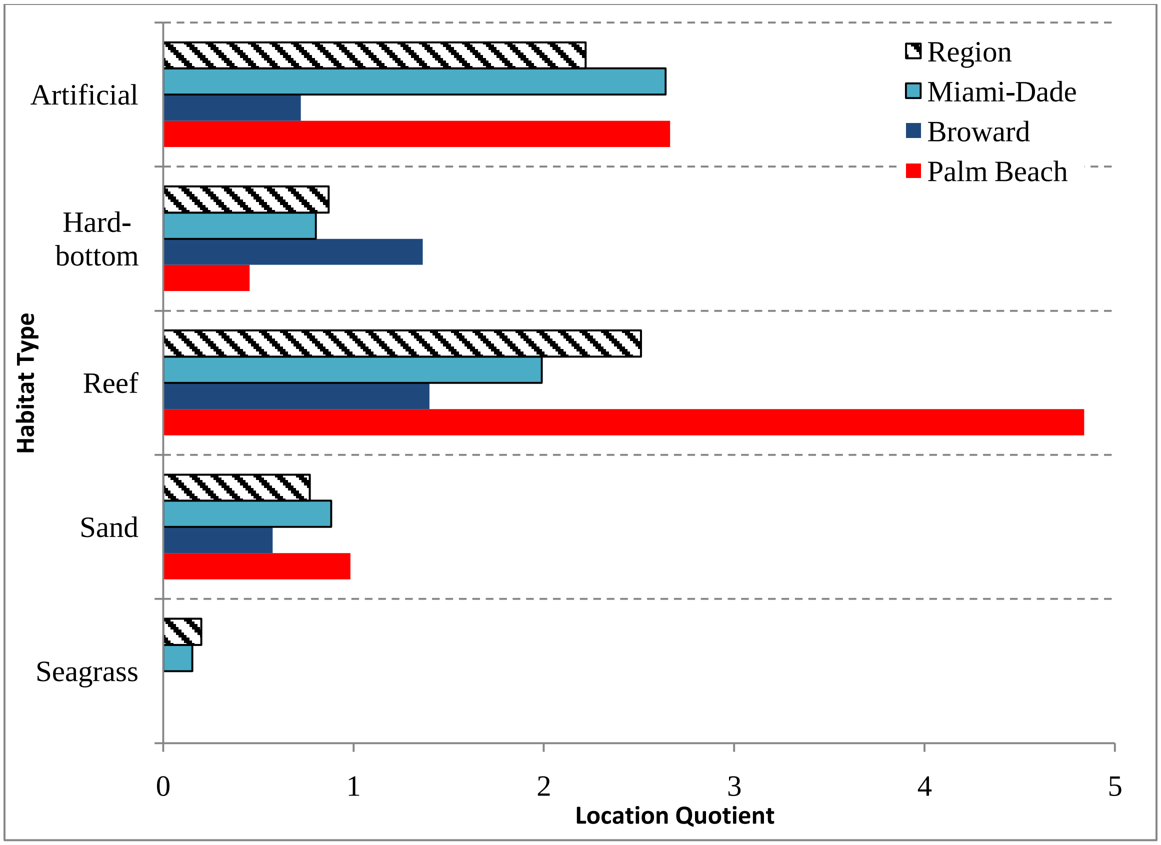

Figure 47. Location quotients of vessels over habitat for each county.

4.3.5 Associations of activities and benthic habitat types

Twenty-four clusters of vessels depicted at distance bands of 800 or 1000 meters in figures 42 to 45 were examined in terms of two activities (diving/snorkeling versus fishing) that vessels could have been engaged in when they were observed. There were a total of 590 vessels, and 66% of them (388) were adrift and 34% were anchored (202). The number of vessels per cluster ranged from 6 to 68 and, depending on the cluster, the number of flights during which the vessels had been recorded ranged from three to nine (Table 13), thus resulting in an average of 1 to 11 vessels recorded per flight (depending on the cluster). The average distance between neighbors in a cluster ranged from 77 meters to 222 meters. In general, most vessels (78.6%) were engaged in fishing and the remainder (21.4%) in diving or snorkeling (Table 13). The percentage of vessels fishing versus diving/snorkeling were consistent when comparing vessels adrift with those anchored. In the case of vessels adrift, 79% were engaged in fishing and 21% in diving/snorkeling. In the case of anchored vessels, 78% were engaged in fishing and 22% in diving/snorkeling.

Table 13. Number of vessels fishing and diving/snorkeling by clusters of vessels.

	County Where Vessel Cluster Located	Number of Vessels by Activity Type					Avg. Nearest Neighbor Distance	Number of Flights
		Diving / Snorkeling	% of Total	Fishing	% of Total	Total		
1	Miami-Dade	1	1.5	67	98.5	68	88	6
2	Palm Beach	10	20.4	39	79.6	49	112	9
3	Palm Beach	0	0.0	42	100	42	130	4
4	Broward	12	32.4	25	67.6	37	152	7
5	Palm Beach	8	21.6	29	78.4	37	155	8
6	Miami-Dade	13	37.1	22	62.9	35	109	5
7	Miami-Dade	1	3.1	31	96.9	32	134	8
8	Broward	12	42.9	16	57.1	28	167	7
9	Broward	11	42.3	15	57.7	26	129	7
10	Miami-Dade	0	0.0	23	100.0	23	136	6
11	Broward	9	39.1	14	60.9	23	157	6
12	Palm Beach	6	26.1	17	73.9	23	77	9
13	Palm Beach	0	0.0	20	100	20	105	8
14	Palm Beach	8	42.1	11	57.9	19	109	7
15	Miami-Dade	7	38.9	11	61.1	18	125	5
16	Broward	10	55.6	8	44.4	18	139	8
17	Miami-Dade	0	0.0	16	100	16	108	5
18	Broward	2	13.3	13	86.7	15	162	6
19	Palm Beach	0	0.0	14	100	14	150	8
20	Broward	7	53.8	6	46.2	13	174	5
21	Palm Beach	4	30.8	9	69.2	13	161	6
22	Martin	4	50.0	4	50.0	8	176	7
23	Martin	0	0.0	7	100	7	223	3
24	Palm Beach	1	16.7	5	83.3	6	148	4
	Totals	126	21.4	464	78.6	590	127	

In general, 47% (279) of 590 clustered vessels were observed over sand, 31% (181) over reef, 18% (109) over hard-bottom, and 4% (21) over artificial reef habitat (Table 14). The distribution of the 202 anchored vessels was similar, with 45% over sand, 35% over reef, 11% over hard-bottom, and 9% over artificial habitat (Table 15). Note that of the 24 clusters examined, 21 included anchored vessels.

Table 14. Number of adrift vessels and anchored vessels by habitat type and by cluster.

County Where Cluster Located	Number of Vessels by Habitat Type				Total
	Artificial	Hard-Bottom	Reef	Sand	
1 Miami-Dade	14	4	24	26	68
2 Palm Beach		11	17	21	49
3 Palm Beach		30		12	42
4 Broward		3	22	12	37
5 Palm Beach		4	21	12	37
6 Miami-Dade	1	3	1	30	35
7 Miami-Dade	1	3		28	32
8 Broward		2	15	11	28
9 Broward	1	4	11	10	26
10 Miami-Dade	1	8	4	10	23
11 Broward		2	12	9	23
12 Palm Beach		1	11	11	23
13 Palm Beach		9	2	9	20
14 Palm Beach	1		8	10	19
15 Miami-Dade	1	3	5	9	18
16 Broward	1		11	6	18
17 Miami-Dade		1	3	12	16
18 Broward		1	5	9	15
19 Palm Beach		1		13	14
20 Broward			7	6	13
21 Palm Beach		8		5	13
22 Martin		7		1	8
23 Martin		4		3	7
24 Palm Beach			2	4	6
Totals	21	109	181	279	590

*The blue highlights indicate, for each cluster (i.e., by row), the relative proportion of anchored vessels that are on each habitat type.

Table 15. Number of anchored vessels by habitat type and by cluster.

County Where Cluster Located	Number of Vessels by Habitat Type				Total
	Artificial	Hard-Bottom	Reef	Sand	
1 Miami-Dade	14	3	19	13	49
2 Miami-Dade	1	2	1	17	21
3 Miami-Dade		2		13	15
4 Palm Beach		1	8	5	14
5 Miami-Dade			3	9	12
6 Miami-Dade	1	3	2	5	11
7 Palm Beach			3	7	10
8 Miami-Dade	1	4	3		8
9 Palm Beach			5	3	8
10 Broward			4	3	7
11 Martin		6		1	7
12 Broward	1		4	1	6
13 Broward			4	2	6
14 Broward			3	3	6
15 Broward		1	3	1	5
16 Palm Beach			4	1	5
17 Palm Beach				4	4
18 Broward			2	1	3
19 Broward			2	1	3
20 Palm Beach				1	1
21 Palm Beach		1			1
Totals	18	23	70	91	202

5.0 Discussion

Understanding vessel use patterns in southeast Florida is essential to applying effective management, especially place-based management (i.e., management focused on a specific geographic area). The resource managers and stakeholders of the Southeast Florida Coral Reef Initiative recognized the need for this information and prioritized this project. The need to associate vessel patterns with spatially explicit benthic features made it particularly challenging, but the methodology we developed yielded many interesting and significant patterns.

5.1 General patterns

Not surprisingly, small (85%) recreational (90%) vessels dominated those observed. Nearly all vessels observed (95%), regardless of their class or size, were either fishing or diving/snorkeling, and many more were fishing (59%) compared to diving/snorkeling (36%). Patterns of anchoring were the primary impetus behind the project as anchoring is a likely and manageable source of reef damage. A third (32%) of all vessels were anchored, 90% of these were < 10 m in length and significantly more recreational vessels were anchored compared to commercial. Furthermore, the spatial analysis revealed that, in general, the incidence of vessels anchored on reef habitat was 2.5 times more frequent than would be expected, given the areal extent of reef habitat as compared to other habitat types. Thus, management targeting this class and size of vessel would likely provide the most return for effort.

Broward County was the only county with an extensive mooring buoy program established at the time of the surveys, which would explain the high frequency of mooring. (Miami-Dade and Palm Beach counties both began mooring buoy installations in 2009 and Martin County had several buoys at the time of the surveys). Palm Beach County had the highest frequency of adrift vessels which could be explained by strong and unpredictable subsurface currents that make anchoring impractical. The use of mooring buoys in Broward County and the practice of drift diving/fishing in Palm Beach County may partially explain the lower frequency of anchoring in these counties compared to Miami-Dade and Martin Counties. The magnitude of vessels observed in Martin County was small compared to the other three counties, thus the magnitude of anchoring was subsequently small. This is likely due to a lower number of registered vessels in Martin County and the time of day Martin County was typically surveyed (late afternoon).

5.2 Use level patterns

The use level treatments significantly affected the vessel use patterns observed, and many of these were logical patterns based on the demographics of the user groups. There were more recreational vessels on weekends/holidays than weekdays and more large vessels (> 20 m) on weekdays. Fishing dominated the activities on weekdays over diving/snorkeling. Use level also had an effect on the frequency of anchoring with more anchoring on weekends/holidays. This is due to more diving/snorkeling and more recreational vessels on weekends relative to weekdays.

Lobster mini-season season had a particularly dramatic effect on use patterns, often altering the statistical outcomes when it was removed. This two-day period brings an exceptionally high number of small, recreational vessels. These vessels are predominantly anchored and diving/snorkeling, presumably for spiny lobsters.

Spatial pattern analysis revealed that the distribution of vessels observed during the mini-season flight was statistically different from that of other flights off all counties except for Palm Beach. In general, vessels observed during the mini-season were closer to shore (in shallower waters) than were vessels observed during the other flights. The mean west-to-east distance between the two distributions was 2.2 km off Miami-Dade County, 1.1 km off Broward County, and 5.0 km off Martin County. The mean distance was 0.4 km for Palm Beach County. The lack of a statistical difference for Palm Beach County is likely due to it containing the narrowest portion of the study area (Fig. 39) and a lack of nearshore hard-bottom.

Further analysis showed that statistically significant clustering of non-mini season vessels occurred in the outer portions of the study area and that these clusters were associated with specific habitat types. A location quotient analysis showed that, when compared to the areal extent of each habitat type, anchored vessels were more highly concentrated (proportionally) on reef habitat than on any other type. The location quotient for anchored vessels over reef habitat was 2.51 (a quotient greater than 1 means that more vessels were observed over the habitat than would be expected given its areal extent). Reef habitat comprised about 10% of the study area whereas 26% of the anchored vessels were observed over this habitat type. In general, the location quotient of vessels over reef was high (2.14), regardless of the vessel status.

Additional analysis was conducted to examine the activities in which the clustered vessels were engaged at the time they were observed. The analysis was an attempt to identify “conflict,” which, for the purposes of this study, was defined as potentially incompatible activities. Fishing and diving/snorkeling were identified as two such activities. Insufficient data, however, limited the ability to make any statements with regard to whether conflict existed or not. This was due to the fact that the 24 clusters examined consisted of vessels that were observed during multiple flights and, on average, during any given flight four vessels were observed per cluster. For example, the cluster with the largest number of vessels, 68, resulted from 6 flights and, on average, 11 vessels that contributed to the cluster were recorded during each of those flights. Furthermore, the average distance between nearest neighbors ranged from 77 meters to 223 meters, and these distances are likely greater if only those vessels from the same flight date were considered. Thus, particularly due to the temporal distribution of the data, it is not possible to indicate whether conflict between activities exists. To do so likely would require that more time than was possible during the helicopter survey be spent at the locations where clusters were detected. Furthermore, since, to a degree, conflict is determined by the perceptions of the boaters themselves, direct contact (e.g., interviews) with them is recommended.

5.3 Study limitations

As with most broad-scale aerial surveys, there must be some compromises due to logistic and fiscal constraints. We attempted to minimize these and limit bias in the data by adopting a repeated method. Funding limited our surveys to ten and provided enough replication to analyze the use level patterns statistically, but did not permit statistical analysis of seasonal use patterns. There was also a spike in fuel prices in 2008 that may have depressed or altered boating activity during the study, but the duration of the study did not allow us to assess this impact.

We sought to survey the entire southeast Florida region during each survey, thereby eliminating day-to-day bias. However, the region is approximately 183 km long, which meant some areas would be surveyed during peak boating hours and others not. Due to the high number of registered vessels, presence of detailed benthic maps, and extensive nature of the reefs in Miami-Dade and Broward Counties, we elected to begin each survey in the south and proceed north. This often led to Martin County not being surveyed until mid-afternoon when many boaters may have headed to port. Finally, our method provided a moving “snapshot in time” of vessel use. It could not capture the variability in use that occurred throughout the day. Only a full-day video recording could do that and the scope of the area makes that impossible.

6.0 Conclusions and Recommendations

The focus of this study was on describing use patterns. Some significant patterns emerged and these findings would be essential in an analysis focused on specific management objectives such as controlled use (e.g., spatial/temporal zoning or activity limitations). However, these data would only be a piece of that analysis and additional factors would be required including current resource condition in the proposed area(s). These results do give a good indication of the anchoring pressure that specific reef segments experience so could serve as a resource for siting mooring buoy locations. Additional studies on the changes in anchoring frequency and location following mooring buoy installation is recommended to assess their ability to change anchoring habits. These data would be a solid baseline for any such study in the near future.

The spatial analysis, while providing statistically significant information on the relative distribution of boats and boating activities, does not provide information about habitat impacts that may (or may not) result. The analysis, however, does provide sufficient information with which to focus future investigations. Given the large spatial extent of the area, the information provided in this report allows the creation of protocols to sample, for example, areas of low to high use. Correspondingly, plots to monitor habitat could be established that are associated with the areas selected to monitor and map use patterns. The additional information generated from such efforts would greatly enhance the ability to develop appropriate management actions.

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8.0 Appendices

8.1 Helicopter flight path

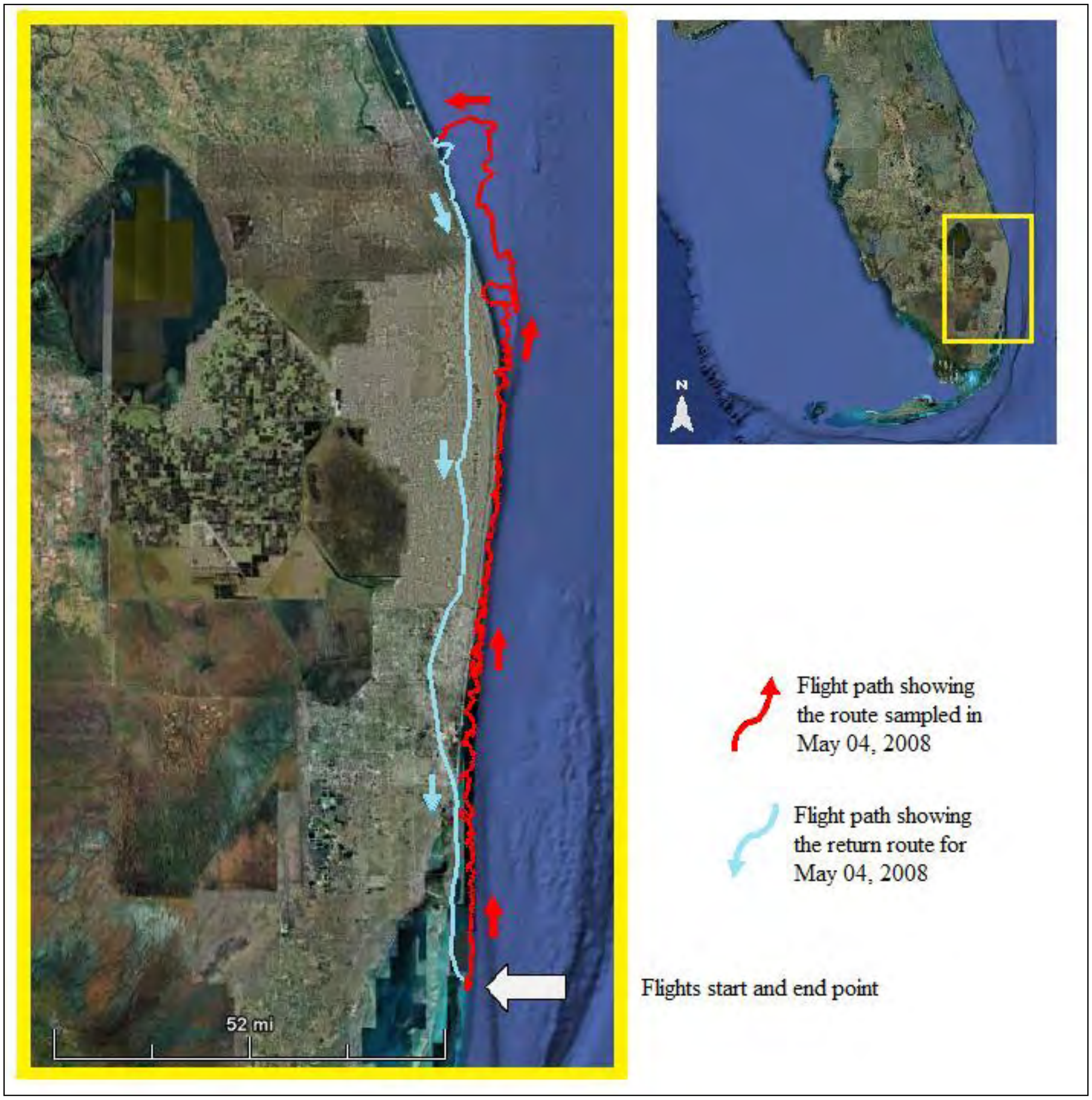

Figure 48. Example of one of the flight routes used for the sample collection during May 04, 2008. Vessels were recorded during the sampled route (red).

8.2 Photo processing methods

Most of the vessel photos were taken using a Canon Power Shot SD950 IS camera; a Canon Power Shot A720 IS and a Nikon E5700 were also used for some photo sets. Standard software (GPS-Photo Link®) was used to assign coordinates to each vessel photo based on photo and GPS time. To correct for discrepancies between the camera and the GPS clock, time offset obtained from a picture of an accurate time source was used in most of the samples. In the field, general descriptions of the vessels were obtained along with the GPS points (e.g., class, size, status, and activity). Those descriptions were used to evaluate the linkage of the pictures with the GPS points produced by the software, and helped to manually modify the coordinates for some pictures that were not matched automatically with the correspondence GPS point because of the general settings used. The descriptions were also used to label the photos. The software produced an ESRI shape file (SHP), Web Page (HTML), and Google Earth (KML/KMZ) files for each sample.

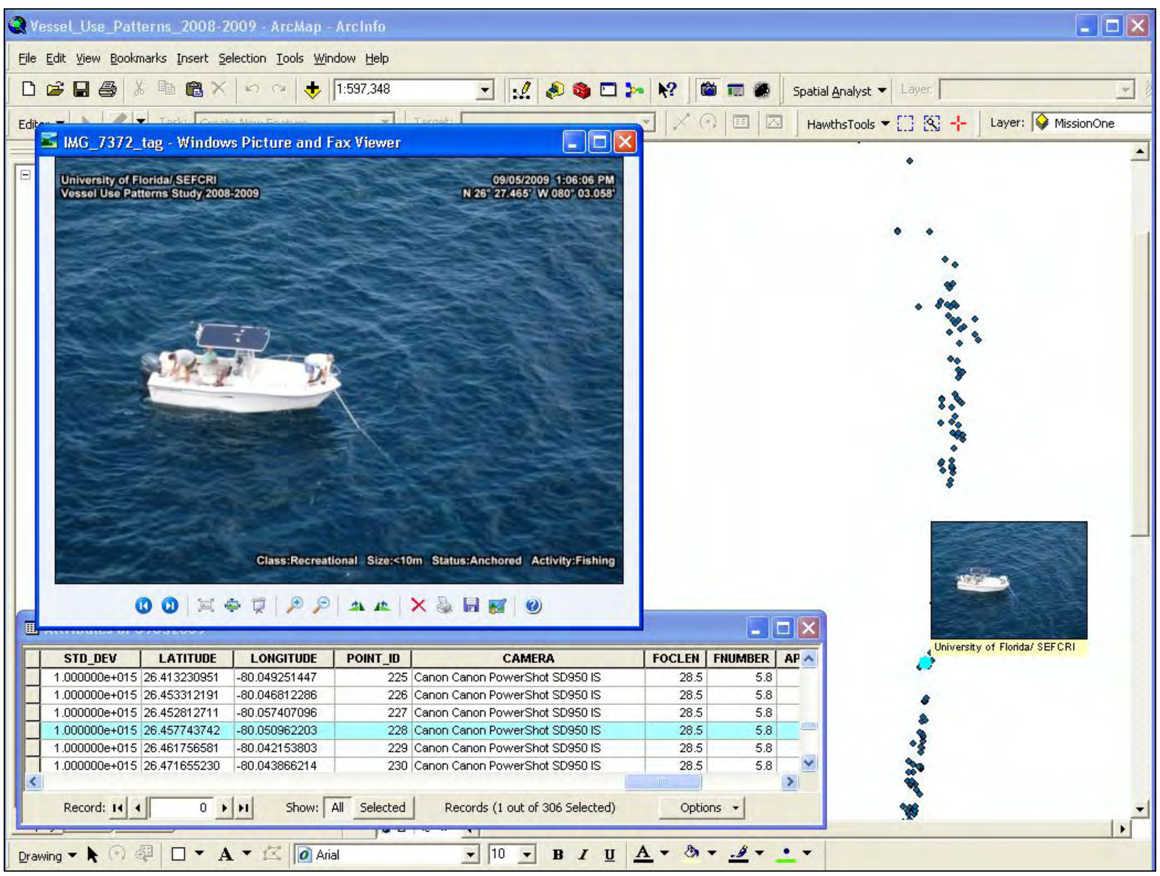

Figure 49. Example of format files produced with GPS-Photo Link software for an ArcGIS® shapefile.

8.3 Locations of anchored vessels in relation to mapped habitat

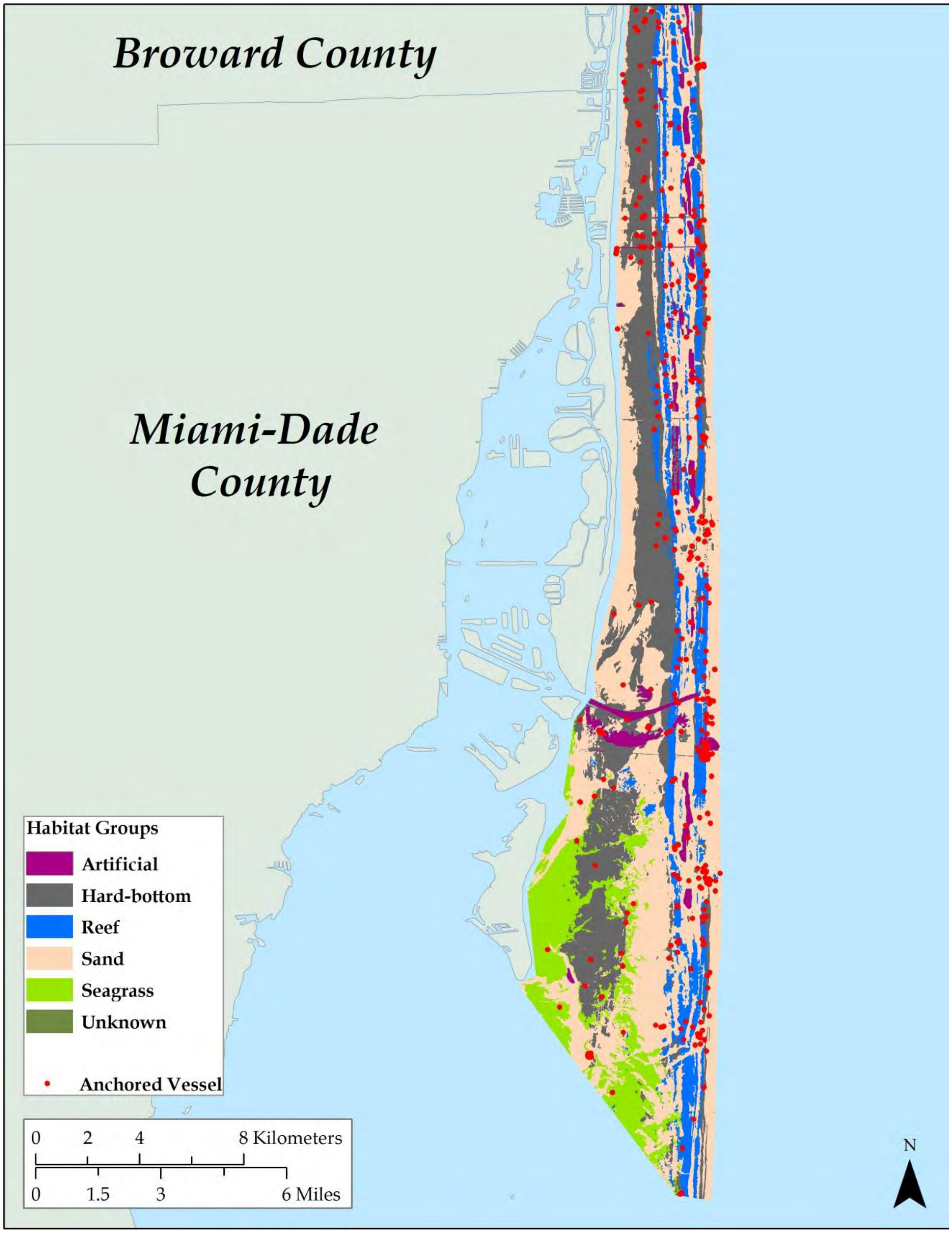

Figure 50. The locations of anchored vessels over benthic habitat off Miami-Dade County.

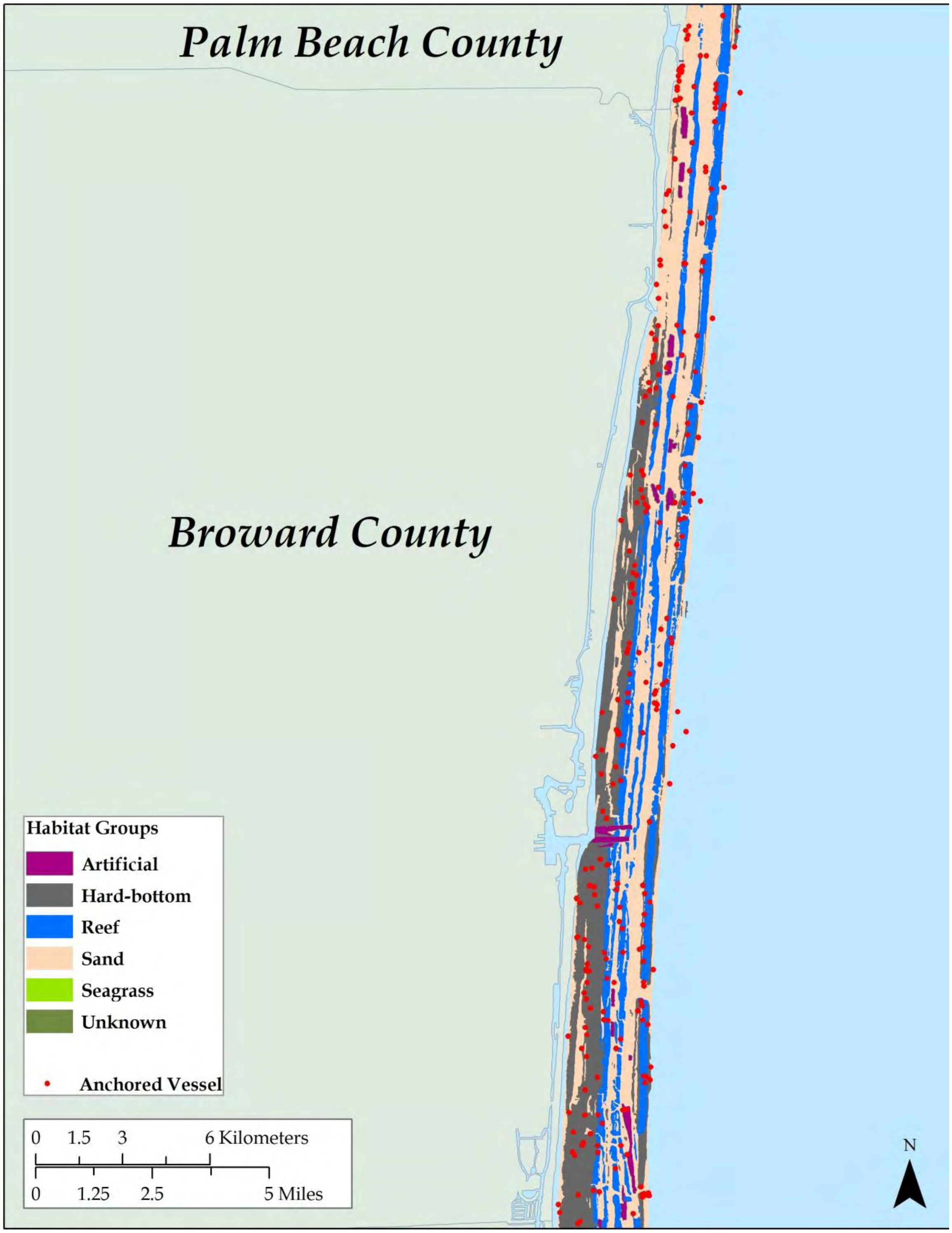

Figure 51. The locations of anchored vessels over benthic habitat off Broward County.

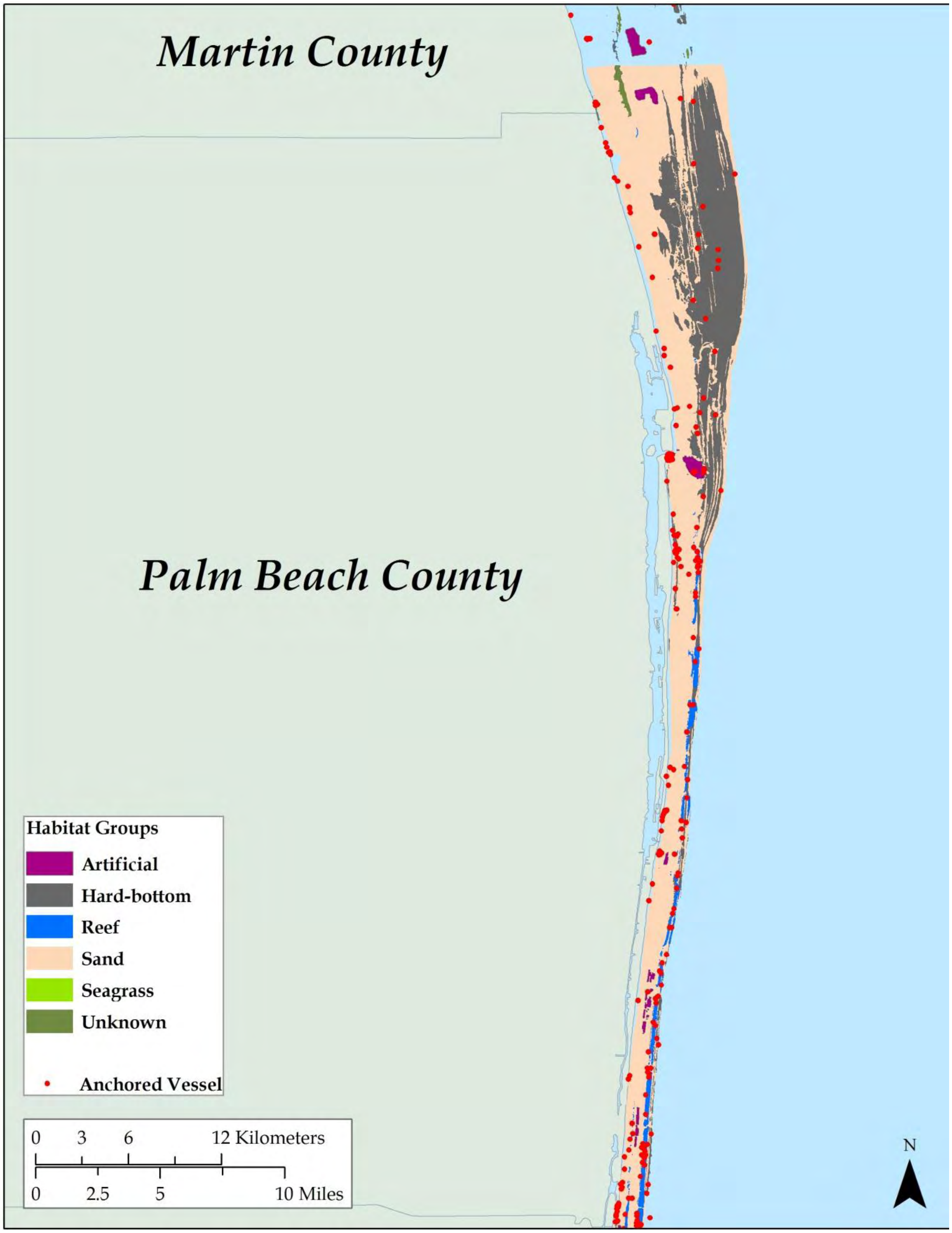

Figure 52. The locations of anchored vessels over benthic habitat off Palm Beach County.

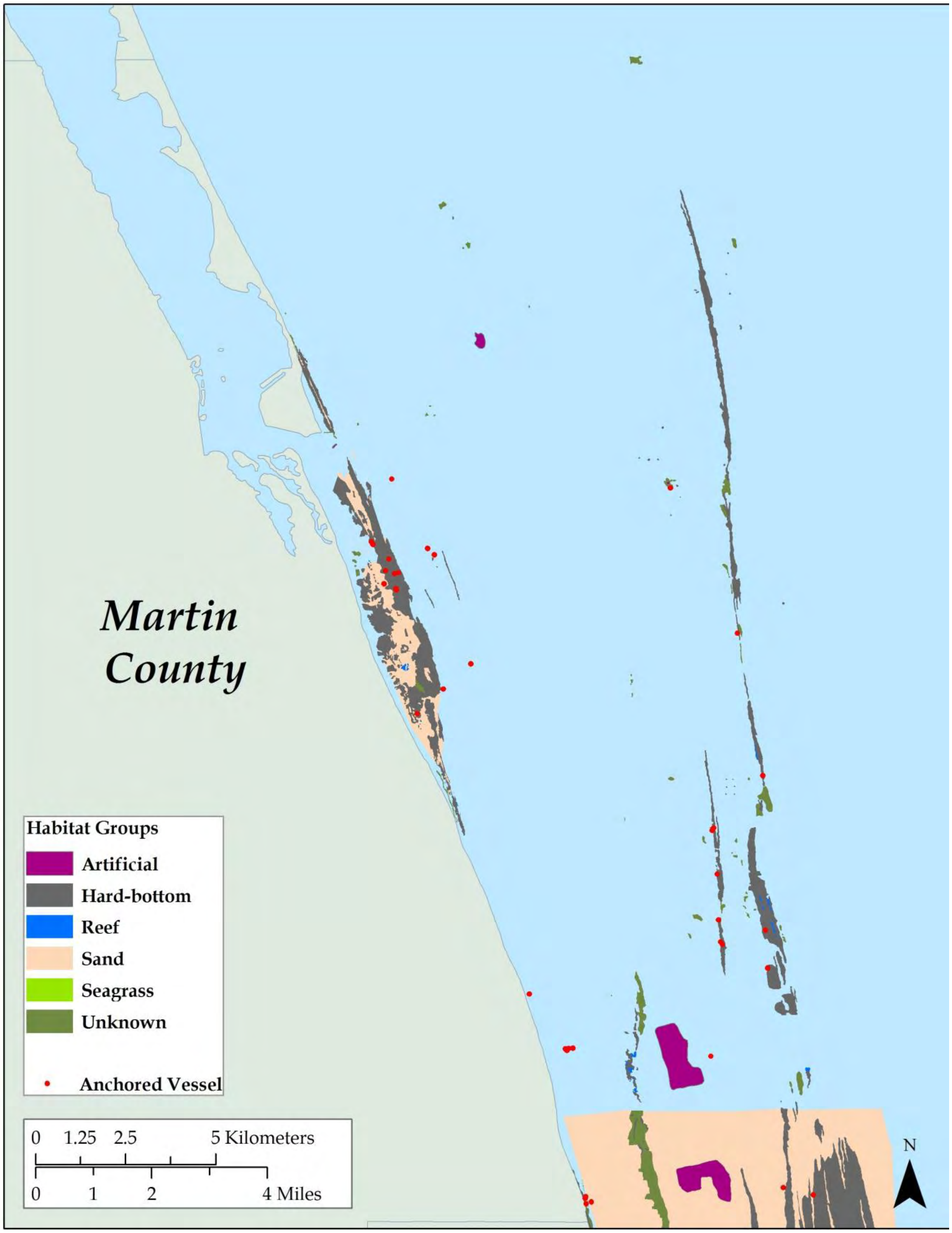

Figure 53. The locations of anchored vessels over benthic habitat off Martin County.