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A Spatial Assessment of Impacts to the Flats Fishery by Recreational Boating in the Florida Keys National Marine Sanctuary

Kristin Anderson

Thesis of
Kristin Anderson

Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Science
Marine Science

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Approved:
Thesis Committee

Committee Chair: Matthew Johnston

Committee Member: David Kerstetter

Committee Member: Ross Boucek

HALMOS COLLEGE OF ARTS AND SCIENCES

A SPATIAL ASSESSMENT OF IMPACTS TO THE FLATS FISHERY BY RECREATIONAL BOATING IN THE FLORIDA KEYS NATIONAL MARINE SANCTUARY

By Kristin Anderson

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Abstract

The recreational flats fishery in the Florida Keys is a significant component of the marine resource-based economy, exceeding $465 million (USD) in annual economic impact. Permit (*Trachinotus falcatus*), bonefish (*Albula vulpes*), and tarpon (*Megalops atlanticus*) are the three main species targeted by flat fishers. Those participating in this fishery generally practice catch-and-release angling therefore, the fishery is considered a more sustainable marine use compared to more traditional commercial fisheries. However, with population and tourism rising in South Florida, the fishery is increasingly threatened by habitat degradation and user conflicts. Ongoing revisions to the Florida Keys National Marine Sanctuary plan creates a unique opportunity to inform management officials of new science describing potential impacts to the flats fishery. This study used a semi-quantitative approach by incorporating local stakeholder information to assess the overlap of flats fishing with boater impacts to better inform management officials of heavily used areas. The extent of flats fishery habitats was compared with multiple anthropogenic stressors such as seagrass propeller scarring, boat ramp locations, and proximity to densely human-populated islands. Results indicated that flats fishing in the Lower Keys was heavily concentrated near bayside mangrove-fringed islands in areas where there was a lower density of seagrass scarring observed. Areas of high scarring included shallow water areas near boat ramps and nearshore areas close to the main islands in the Lower Keys. Ongoing revisions for the Restoration Blueprint provide ample opportunity to deliver the information from this study to help ensure the stability of an economically valuable and culturally important fishery.

Keywords: Flats Fishery, Florida Keys National Marine Sanctuary, Marine Special Area, Propeller Scarring, Seagrass

Acknowledgments

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The strength and desire needed to reach my professional goals was maintained through the limitless love and support of my friends and family. My parents, Maryann and Bob Anderson, have always encouraged me in the pursuit of all my achievements. Joshua Farmer, I could have never reached this point without your love and encouragement. Finally, I dedicate this work to those who have taught me how to read a book, solve an equation, chase the sun, sleep under the stars, smile, laugh out loud, laugh at myself, find my voice, work hard, play harder, cast a lure, hold a hammer, drive a tractor, drive a boat, SCUBA dive, hike through the slough, catch the wind, catch a wave, and to never, ever stop learning. To all those who have been a part of my journey, I thank you.

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1.0 Introduction

A Geographic Information System (GIS) provides the means to efficiently collect, store, analyze, manipulate, and display spatially referenced data that contains both geometry data (coordinates and topological information) and attribute data (descriptive data) (Bunch et al. 2012; Soden and Steel 1999). GIS allows for the development of useful tools to spatially understand the status and trends of natural resources which are particularly important for marine conservation (Gaines et al. 2010; Strickland-Munro et al. 2016) in areas such as the Florida Keys. Approximately 60 percent of jobs in the Florida Keys are connected to the marine ecosystem and over $3 billion (USD) in sales and income (Office of National Marine Sanctuary 2019). As anthropogenic stressors continue to increase and threaten the Florida Keys, Marine Spatial Planning (MSP) is a method being used by management officials to spatially allocate areas with the intention to protect declining resources, regulate ecosystem goods and services, and balance competing uses (Noble et al. 2019). Using MSP allows management officials to understand the social and ecological relationship between people and the marine environment which is essential for effective planning and management (Noble et al. 2019; Strickland-Munro et al. 2016; Vanessa Stelzenmüller et al. 2013).

Marine Protected Areas (MPAs), are a known form of MSP which are based on balancing human demands and protecting areas that support ecosystem function (Noble et al. 2019). Defined by the ICUN a MPA is "a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" which includes no-take-zones, limited access zones , sanctuaries, and ecological reserves. (Jessen et al. 2017; Day et al. 2012). MPAs provide protection for critical habitats and endangered species while also serving important roles in public education and outreach relative to other more traditional management measures such as harvest regulations (Edgar et al. 2014; Agardy et al. 2003). Conservation benefits can be measured through the increase of fish stock and biodiversity and the overall abundance of threatened species and habitats (Edgar et al. 2004; McClure et al. 2020; Lubchenco et al. 2003; Gaines et al. 2010). For instance, after the establishment of MPAs in the Republic of Maldives large-fish biomass improved and ultimately led to a rise in wildlife tourism yielding over $2 million (USD) more for the economy (Cagua et al. 2014). Thus, MPAs can provide key social, ecological, cultural, and economic benefits by mitigating spatial use conflicts and fostering an ecosystem-based approach to marine governance (Agardy et al. 2003; Stelzenmüller et al. 2021).

The Florida Keys Archipelago in the southeastern United States is a tropical marine environment known for its world-class diving and fishing opportunities. Marine resources support 44 percent of the jobs for the Florida Keys region (Rockport Analytics 2019) and a "laid back, anything goes" attitude has shaped a local culture that continuously draws in tourists (Clarke 2002). In recent years, tourism has exponentially increased from 3.64 million visitors per year in 2008 (Office of National Marine Sanctuaries 2010) to over 5.13 million visitors per year in 2019 (Rockport Analytics 2019). While most visitors to the Florida Keys enjoy the abundance of marine resources by either boating, fishing, or diving, an increase in boating activity puts coastal and nearshore habitats at risk of damage due to irresponsible or uneducated marine use. Previous studies have identified a substantial number of negative impacts related to increasing human population density and human accessibility to marine environments on marine resources (Rees et al. 2021; Cinner et al. 2018; MacNeil et al. 2020; Stuart-Smith et al. 2008). The high social and economic reliance of marine resources to the Florida Keys community provides an ideal scenario for comprehensive spatial management approaches to maintain the resilience of the resources.

1.1 Focal System: Florida Keys National Marine Sanctuary

Congress designated the Florida Keys National Marine Sanctuary (FKNMS) in 1990 as part of the National Oceanic and Atmospheric Administration's (NOAA) National Marine Sanctuary Program (Suman et al. 1999). Encompassing 9,515 km^2 in area, the FKMNS extends from the Florida peninsula to the south (Key Largo) and west to the Dry Tortugas (Figure 1). The FKNMS was established as the nation's first comprehensive network of marine zones in 1997, designed to protect and preserve sensitive parts of the ecosystem while allowing activities that are compatible with resource protection (Office of National Marine Sanctuary 2019). The Sanctuary's marine ecosystem supports over 6,000 species of plants, fishes, and invertebrates, encompasses North America's only coral barrier reef and includes one of the largest seagrass communities in the northern hemisphere (Office of National Marine Sanctuaries 2011).

Numerous stakeholder groups and non-profit organizations play a role in the marine environmental politics of the Florida Keys (Suman et al. 1999). Recognizing the need and urgency to address declining flats fishery habitats and a perceived decline in bonefish and tarpon, in 1998, Bonefish

& Tarpon Trust (formerly known as Bonefish & Tarpon Unlimited) was formed by anglers, fishing guides, and members of the recreational flats fishery (Adams and Cooke 2015). Today, Bonefish & Tarpon Trust is a science-based, non-profit organization comprised of local stakeholders dedicated to conserving bonefish, tarpon, and permit through research, stewardship, education, and advocacy (BTT 2021). Collaborating with Bonefish & Tarpon Trust, the Lower Keys Guides Association is a non-profit organization of professional fishing guides dedicated to working for a sustainable resource through wise management practices while recognizing the importance of sport fishing to the economy and cultural heritage of the Florida Keys (LKGA 2020). These two organizations work towards uniting scientists, anglers, and the recreational fishing sector to raise awareness and increase the conservation of bonefish, tarpon, and permit, along with the increasing interactions between the scientific and angling communities (BTT 2021; Adams and Cooke 2015). Both Bonefish & Tarpon Trust and the Lower Keys Guides Association have long lobbied state and federal government agencies for increased protection of the flats fishery in the Florida Keys.

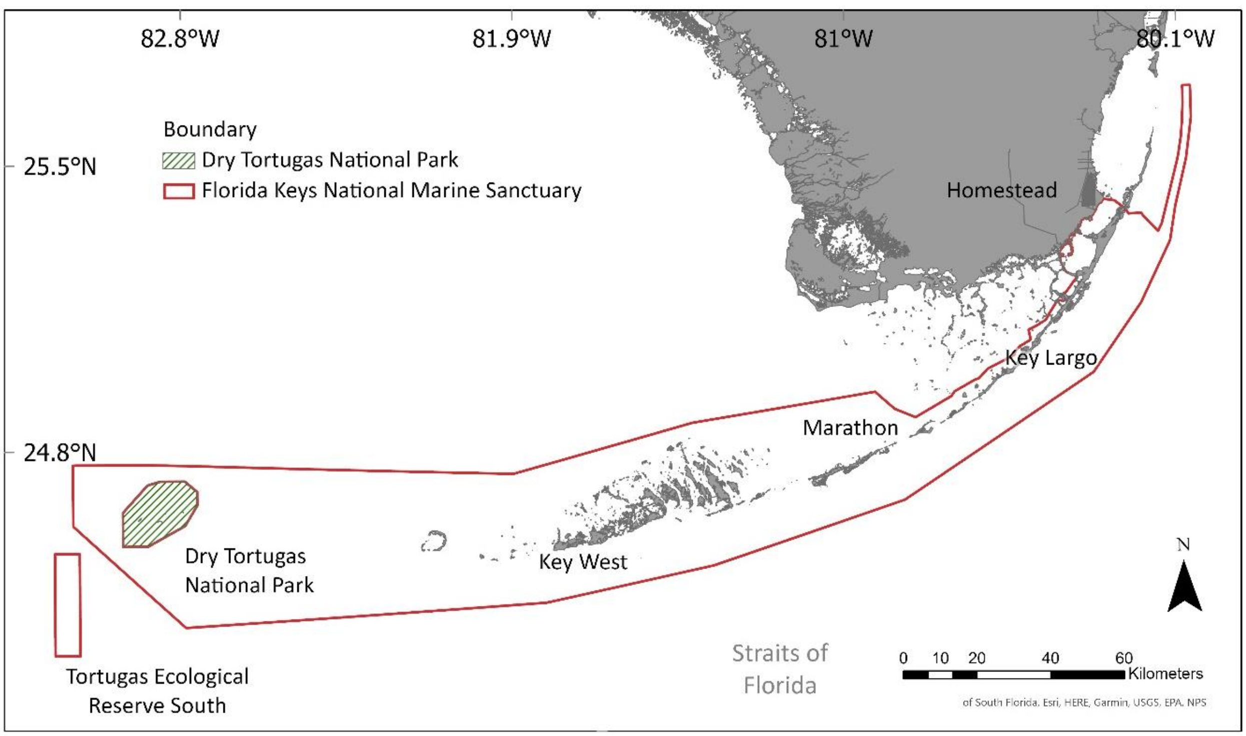

Figure 1: Florida Keys National Marine Sanctuary boundary. The boundary does not include the Dry Tortugas National Park.

The Florida Keys archipelago is mainly managed by four government agencies including the U.S. Fish and Wildlife Service, NOAA, the Florida Department of Environment Protection, and the Florida Fish and Wildlife Conservation Commission, while multiple state and federal agencies, universities, and non-government organizations provide management through scientific research. The FKNMS management philosophy is to protect the surrounding resources, such as coral reefs, shipwrecks, seagrass, and fisheries by the use of local stakeholder input, scientific research and socioeconomic data. In recent years, southern Florida has experienced rapid and substantial growth of human populations and coastal development (Larkin et al. 2010). Despite these additional stresses, management to the FKNMS has not changed accordingly to maintain a resilient system. Since implementation, NOAA updated the FKNMS marine zone regulations to include the Tortugas Ecological Reserve in 2001, added a no-discharge zone regulation within federal waters in 2010 (Florida state waters were designated as no-discharge in 2002), and updated non-regulatory management plan activities in a 2007 revised management plan (Office of National Marine Sanctuaries 2019). However, in 2019, the FKNMS proposed revisions to further the existing sanctuary management plan using a variety of management measures based on the 2011 FKNMS condition report (Office of National Marine Sanctuaries, 2019). The FKNMS developed the Restoration Blueprint which includes multiple proposed action plans with the intent to help counteract the decline of natural resources by expanding on the management regulations (Office of National Marine Sanctuaries 2019). This blueprint includes four alternative plans. Alternative One (current regulation) encompasses 3,800 square miles and includes 28 wildlife management areas, 19 sanctuary preservation areas, four special use areas, two ecological reserves, and four existing management areas for a total of 57 marine zones (Figure 2). Alternative Two expands the boundary to 4,541 square miles and adds 31 wildlife management areas, six sanctuary preservation areas, and two conservation areas compared to Alternative One (Figure 3). Alternative Three (preferred alternative) expands the boundary identical to Alternative Two and adds 32 wildlife management areas, seven sanctuary preservation areas, and two conservation areas compared to Alternative One (Figure 4). Alternative Four expands the boundary to 4,800 square miles and adds 32 wildlife management areas, three sanctuary preservation areas, and seven conservation areas compared to Alternative One (Figure 5) (Office of National Marine Sanctuaries 2019).

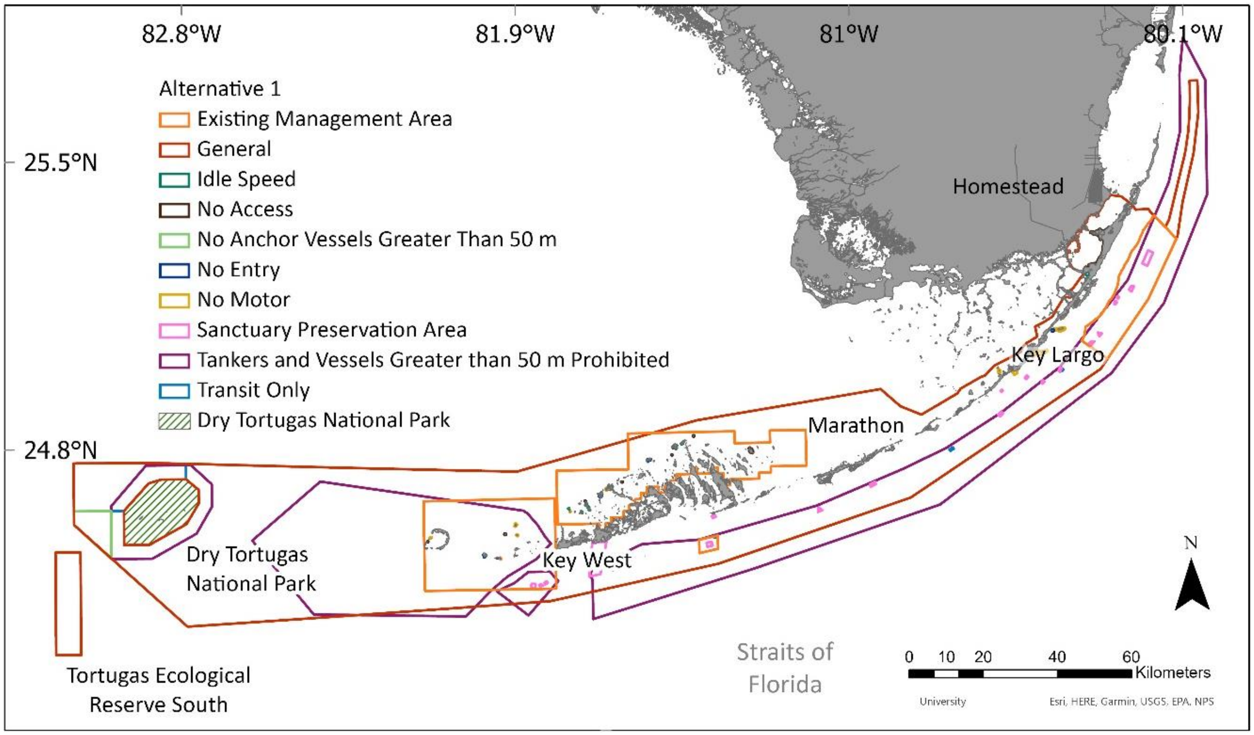

Figure 2: Map showing the current regulations and management zones of the FKNMS (Alternative One).

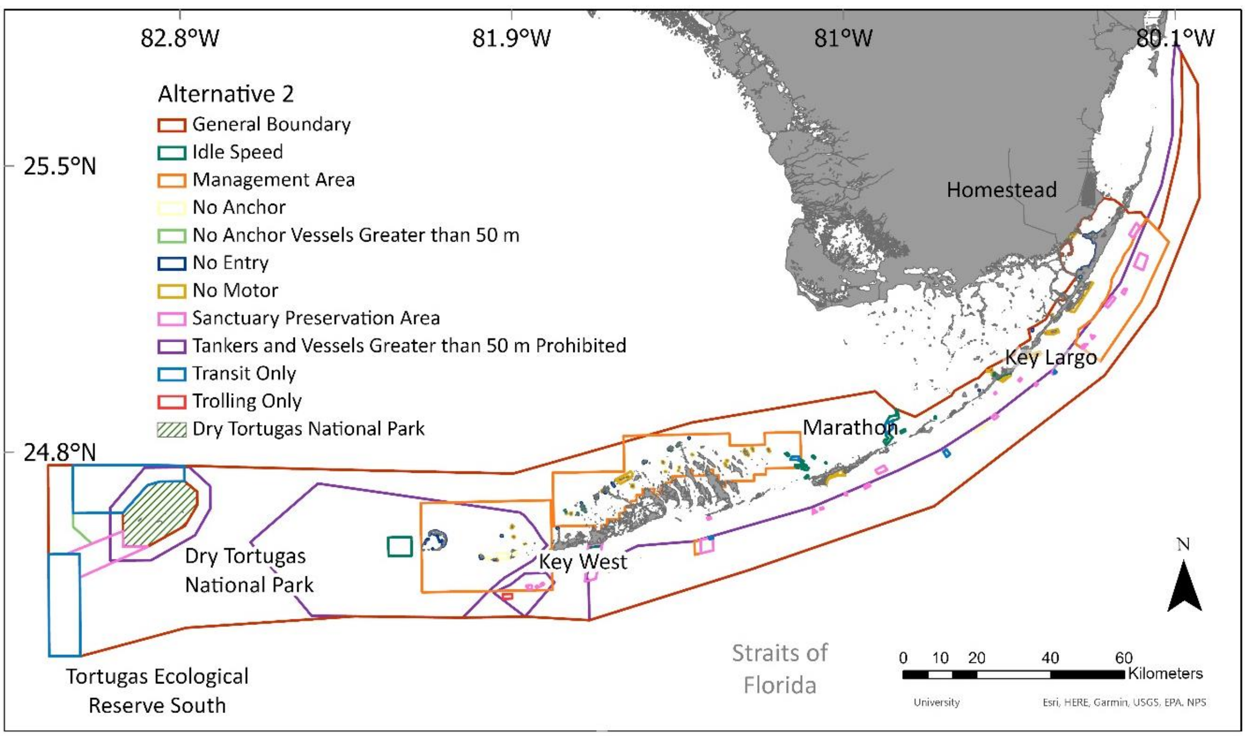

Figure 3: Map showing the proposed regulations and management zones of Alternative Two.

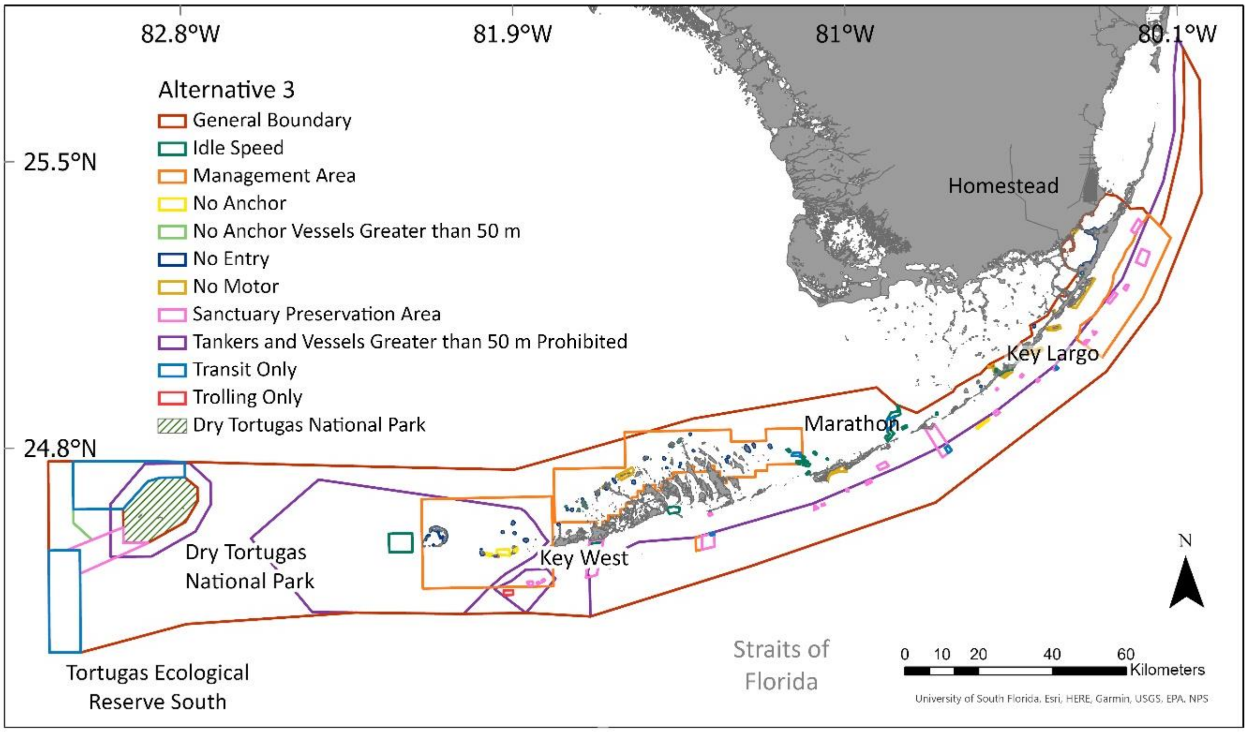

Figure 4: Map showing the proposed regulations and management zones of Alternative Three.

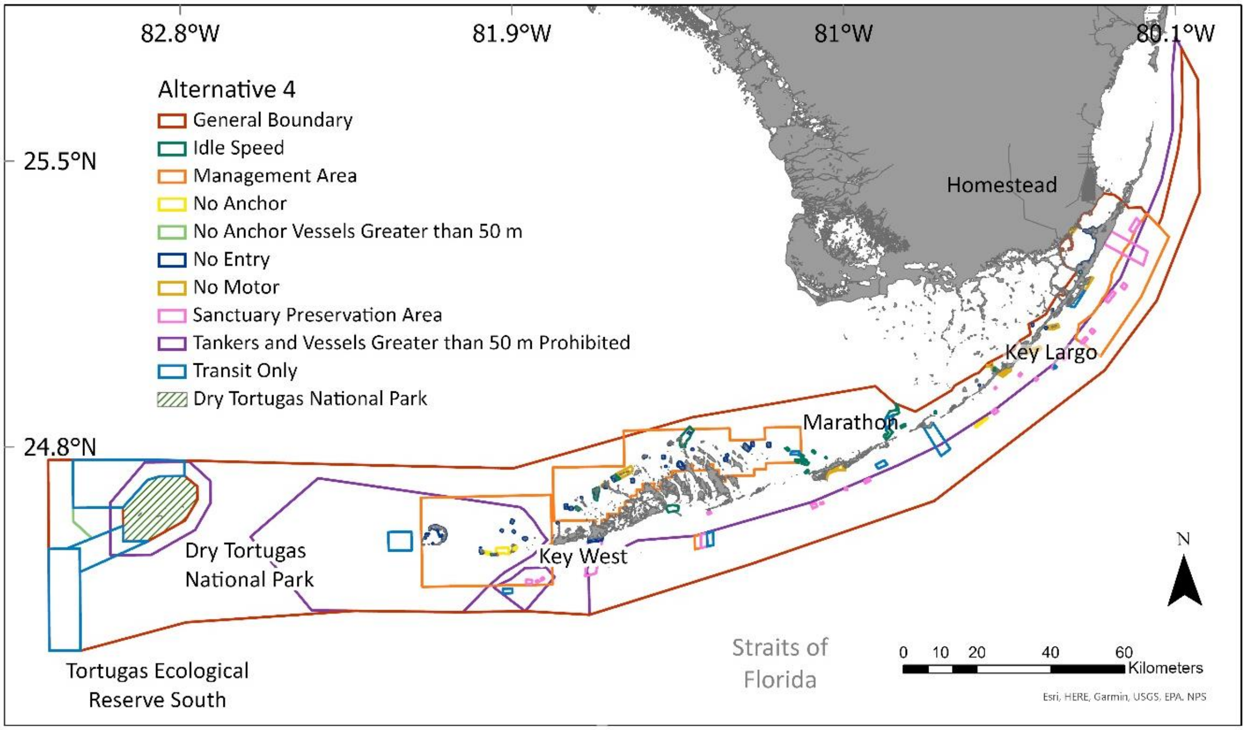

Figure 5: Map showing the proposed regulations and management zones of Alternative Four.

1.2 Focal Resource: Flats Fishing

Recognized as the birthplace of flats fishing (Black et al. 2015; Frezza and Clem 2015), the Florida Keys recreational flats fishery is a major component of the resource-based economy exceeding $465 million (USD) in annual economic impact and provides over 8,000 jobs (Fedler 2013). The recreational flats fishery mainly occurs in the shallow (<2m) habitats of marine tropical and sub-tropical regions which include, seagrass, mangroves, sand and mud bottom, hardbottom, and macroalgae collectively recognized as the flats (Adams et al. 2019; Black et al. 2015). Those participating in this fishery generally use sustainable fishing techniques, such as fly fishing (expending high energy for a low yield), while practicing catch-and-release angling (Adams et al. 2019). The recreational flats fishery includes red drum (*Sciaenops ocellatus*), jack crevalle, (*Caranx hippos*), and snook (*Centropomus undecimalis*) but permit (*Trachinotus falcatus*), bonefish (*Albula vulpes*), and tarpon (*Megalops atlanticus*) are the three main species targeted by flats fishers in the Lower Keys (Adams and Cooke 2015). Compared to the conservation efforts of snook (restocking initiative) (Rutger 2018), little effort has been directed toward the conservation of bonefish, tarpon, and permit even though many anglers have noted a decline in the abundance and size of these species throughout the years (Santos et al. 2017; Rehage et al. 2019; Santos et al. 2019).

Permit are found in the western Atlantic from Massachusetts to southern Brazil, throughout the West Indies and in Bermuda (Armstrong et al. 1996) but are most common year-round in coastal waters of the Caribbean and Gulf of Mexico (Bohlke and Chaplin 1993; Adams et al. 2006). Adult permit mainly inhabit seagrass and tidal sand flats and channels but can also be found offshore on coral reefs and artificial structures (Holder et al. 2020) Recently, Brownscombe et al. (2020) documented that permit in the Florida Keys most likely utilize flat habitats for foraging and relocate farther offshore to spawn near structures such as reef promontories and wrecks on the Florida Reef Tract. While there has been a push by scientists to protect these spawning aggregation sites in the FKNMS (BTT 2019; Brownscome et al.2019), the high fishing pressures on permit suggest the need for a broad-scale conservation management plan to sustain the fishery (Adams and Cooke 2015; Holder et al. 2020).

Tarpon are one of the most sought-after inshore marine game fishes for anglers across the globe (Luo et al. 2020). Tarpon is a large, migratory species that frequents coastal and inshore waters of the tropical and subtropical Atlantic Ocean and occurs in a variety of habitats ranging from nearshore flat habitats to offshore marine waters (Crabtree et al. 1997). Juveniles mainly use mangroves and marsh systems as nursery habitat and feed upon zooplankton, small crustaceans, and insects (Adams and Cooke 2015), while adults typically migrate to deeper-water habitats and feed on larger crustaceans (penaeid shrimps, swimming crabs) and a variety of fish (Adams and Cooke 2015; Whitehead and Vergara 1978). A recent study on the migration and movements of tarpon suggests that habitat loss is a more insidious threat to the sustainability of the fishery (Griffin et al. 2019; Luo et al. 2020). However, there is a general lack of spatial coverage data and stock condition relative to anthropogenic impacts (Wilson et al. 2019).

Historically, bonefish were considered to be a single species (*Albula vulpes*), however in 2001, new genetic data suggested that there are distinct species (Cooke and Philipp 2004; Colborn et al. 2001). Members of the bonefish genus (*Albula*) are found throughout the world's shallow tropical seas targeted by anglers worldwide generating important revenue for many local economies (Brownscombe et al. 2013; Cooke and Philipp 2004). In the FKNMS, *Abdula vulpes* is the most commonly encountered species (Colborn et al. 2001). Bonefish predominately feed on benthic invertebrates and small fishes, while foraging in less than 0.3-meter-deep water where their tails and dorsal fins can be seen extending from the water (commonly known as tailing) (Crabtree et al 1998; Brownscombe et al. 2019). Because bonefish, tarpon, and permit are known to use the entire coastal habitat throughout their life they are also valuable umbrella species for broad-scale conservation (Adams et al. 2019).

Since bonefish, tarpon, and permit collectively rely on shallow water flats which generally occur in close proximity to the populated Florida Keys islands, the number of interactions between this fishery, the habitats that support the species, and other marine users can be high. These interactions often lead to unintended consequences such as habitat destruction caused by boat propellers and vessel groundings in seagrass habitats. Seagrasses within the FKNMS are particularly susceptible to vessel damage as they often occur at depths < 2 m and as a result, vessel damage now ranks as a major source of habitat destruction (Furman et al. 2019). The FKNMS is one of several management entities responsible for the fisheries and habitat protections. However, in 1995, an estimated 30,000 acres of seagrass in the FKNMS were impacted by boat propellers, which almost doubled in 2015 to 60,000 acres (Kruer 2017). Recent studies suggest that 300 to over 650 boat groundings occur annually within the FKNMS, with up to 80% taking place in seagrass habitats (Kirsch et al. 2005; SFNRC 2008; Farrer 2010; Furman et al. 2019). Prop scars lead to a direct loss of seagrass and sediment, leaving the injured beds vulnerable to further damage from boat wakes, currents, and severe storms (Furman et al. 2019; Whitfield et al. 2002). Consequently, seagrass recovery from vessel damage can take decades (Andorfer and Dawes 2002; Kenworthy et al. 2002; Whitfield et al. 2002; Uhrin et al. 2011; Furman et al. 2019), and model-derived estimates of recovery in *Thalassia testudinum* (turtle grass) beds suggest that some areas in the Florida Keys may require 60 years for recovery (Hallac et al. 2012; Fonseca et al. 2004).

As annual tourism in the Keys continues to increase, habitat destruction is an increasingly predominant issue for the sustainability of the flats fishery. Seagrass scarring can be reduced with established marine protected areas (Office of National Marine Sanctuaries 2011), proper navigational aids (e.g., buoys, channel markers), and education about the risks and impacts to the habitats (Barry et al. 2020). For example, 18 years after the FKNMS established a no-motor zone at Tavernier Key, much of the seagrass has been restored (Figure 6). Despite this success story, the FKNMS condition report (2011) concluded that most marine resources were in fair or poor conditions with a stable or declining trend. Thus, FKNMS's existing regulations, marine zones, and management plans created in 1997 are no longer sufficient to address the current widespread and emerging threats to marine resources (Schwarzmann et al. 2022). However, marine spatial planning can provide an overarching framework to explicitly address and integrate socio-economic approaches to help ensure the stability of these species since bonefish, tarpon, and permit form a culturally and economically important fishery in south Florida.

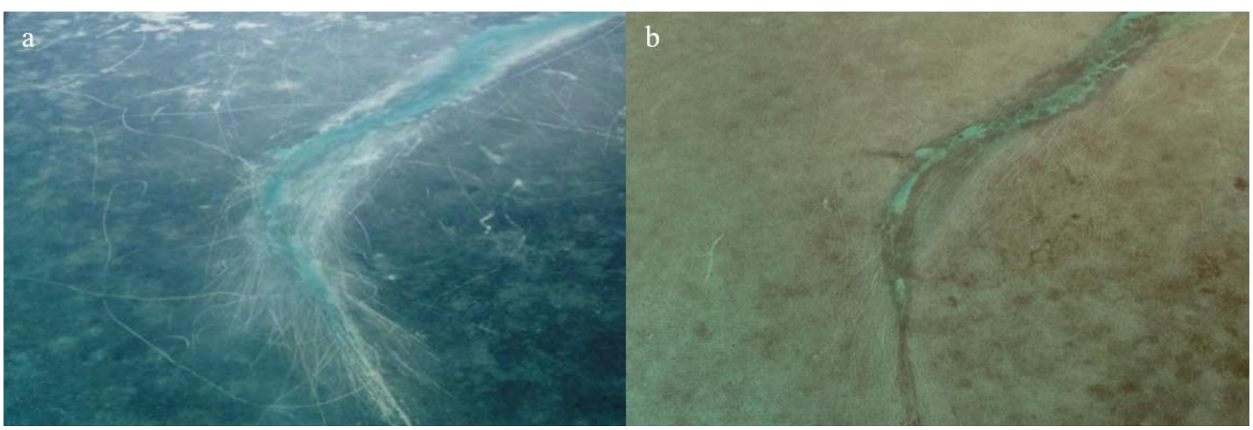

Figure 6: Aerial imagery of Tavernier Key (a) in 1998 and (b) in 2017 showing the change in vessel damage after the FKNMS established a no-motor zone.

1.4 Study Aims

Following Black et al. (2015), this study used a semi-quantitative, expert-based approach to incorporate local stakeholder information to gather spatial fishing coverage in the Lower Keys. Though gathering spatial fishing information relies heavily on the fisher's accuracy and may contain errors (Gervasi et al. 2022; Pauly 1995), the methods used represent the best approach to gathering spatial data on the primarily catch-and-release flats fishery (Black et al. 2015). Current, ongoing revisions to the Florida Keys National Marine Sanctuary management plan, creates a rare opportunity to inform officials about impacted areas which affect the flats fishery (Black et al. 2015). Specifically working with local fishing guides to quantify fishing coverage can improve data quality and help fill the gaps of information. Using spatial fishing coverage data, two key objectives of this study were to:

1. determine overlapping locations of high fishing activity with seagrass scarring to suggest MPAs to management officials
2. assess potential relationships between seagrass scarring density and location of scarring when analyzed against proximity to boat ramps and shoreline

In order to implement effective marine management strategies, managers must understand the relationship between prop scar conditions and potential associations with causing factors including boat ramps along with the areas that negatively affect the sustainability of the local flats fishery. Results from this study will be provided to the local guides who participated with the intention to collaboratively select areas that will effectively protect the resources needed to further sustain the fishery. Those areas will then be given to the FKNMS management officials during the revision process.

2.0 Methods

ESRI ArcGIS Pro 2.8.0 was used to document spatial fishing coverage and impacts to the flats fishery. The study focused on the Lower Keys (Figure 7) because the flats fishing community is more active in the Lower Keys compared to the Upper and Middle Keys. Spatial fishing data was obtained from active, full-time fishing guides who participated in a previous project conducted by Black et al. (2015). In the Black et al. (2015) study, participants were asked to record with a marker on a physical map where they fished for bonefish, tarpon, and permit. Participants were also asked to delineate between species using different colored markers. Due to the sensitive nature of the data and to further protect the fishers' livelihood, all parties privy to the fishers' maps signed a non-disclosure agreement.

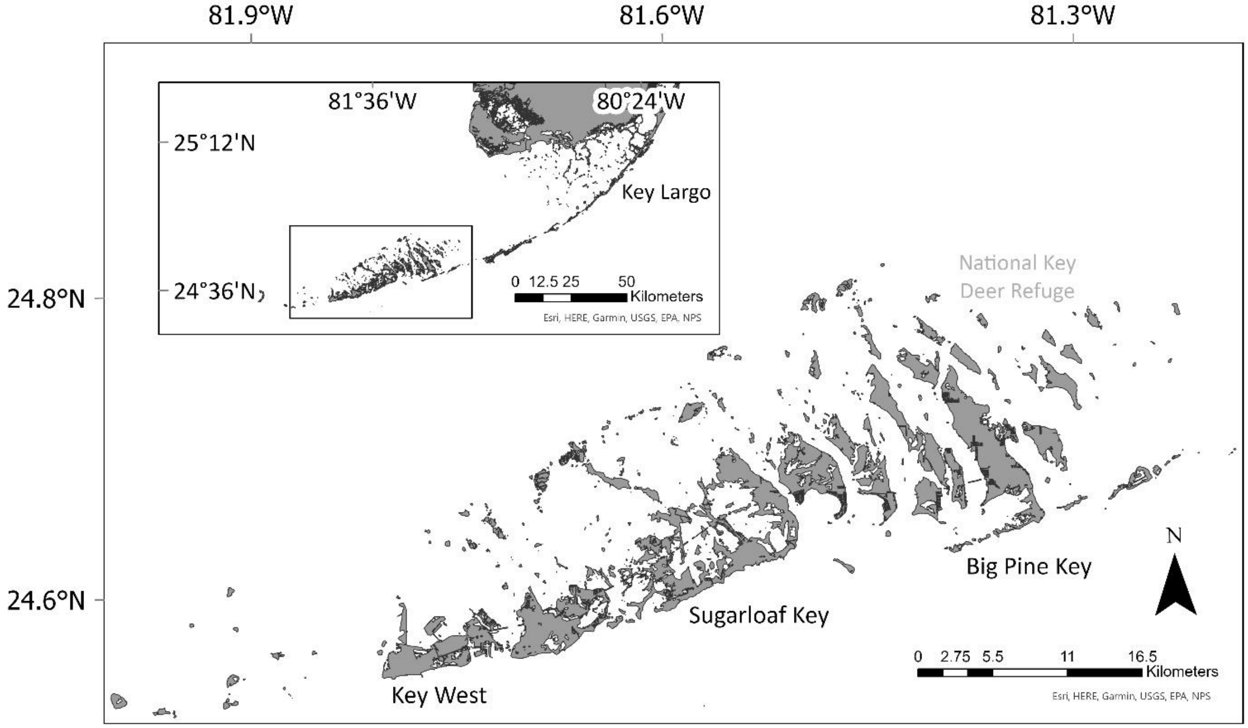

Figure 7: Map of the Lower Keys which represents the study area.

2.1 Fishing Usage Map

Maps from participants were scanned into digital copies and georeferenced by aligning geographic features of the raster image with the matching geographic features on a reference map (WGS 1984). The images were manually georeferenced using an average of 8 control points, including unique geographic features in the Lower Keys, such as Key West VORTAC EYW 113.5 Beacon (24.5858, -81.8004), Little Palm Island Resort (24.6239, -81.4011), Edward B. Knight Pier (24.5452, -81.7834), and the northernmost tip of Big Pine Key (24.7450, -81.3958 (Figure 8). Error is possible when manually aligning the raster images to the reference map due to the likelihood of human error along with the low resolution (cell size >15 m^2) of the scanned maps compared to the WGS 1984 reference map.

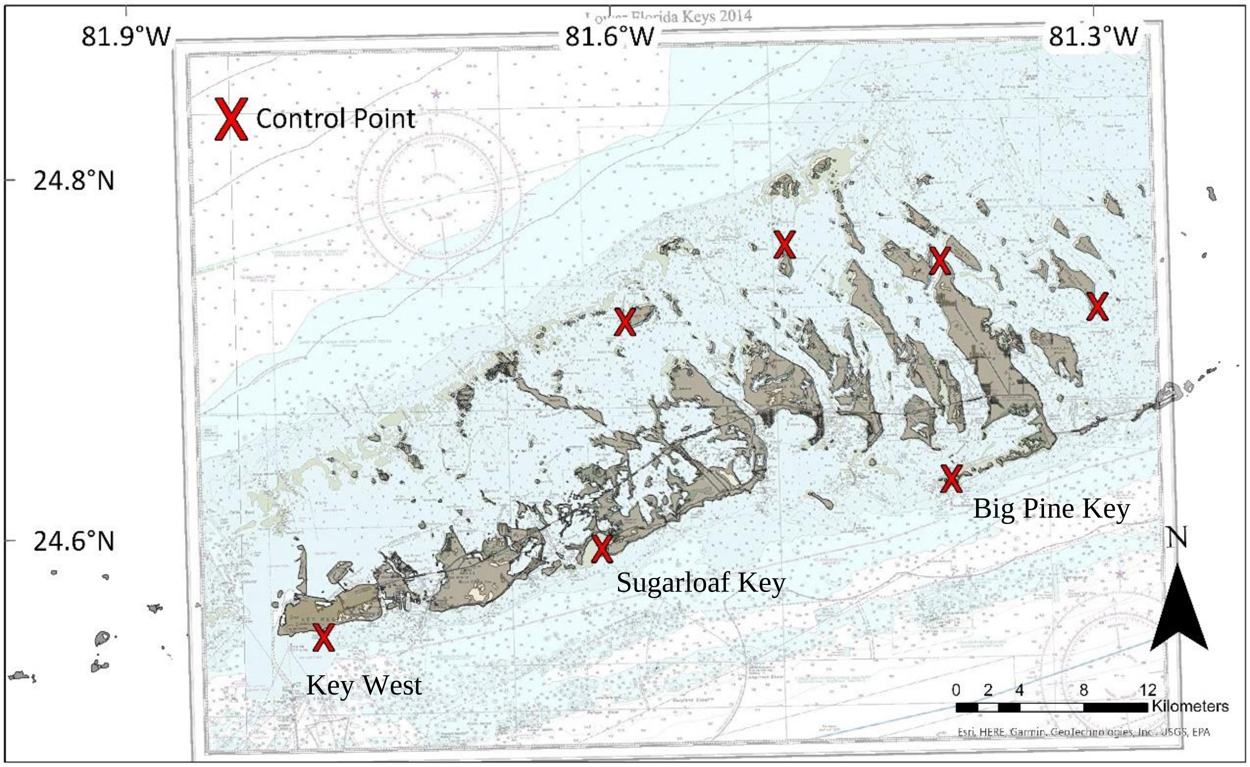

Figure 8: Illustration of a georeferenced map. The reference map was overlaid with a fisher's map to align geographic features.

Fishing areas were digitized manually by tracing the fishing areas corresponding to each fisher's map using the edit and sketch tool. Bathymetric contours were used to guide the fishing area boundaries focusing on areas in water depths of < 2m as previous research suggests seagrass scarring mainly occurs in shallow depths (SFNRC 2008; Furman et al. 2019). Once digitized, all individual maps were merged into one composite layer with polygons representing each fishing area. Each resulting polygon was labeled with a unique ID corresponding to an individual fisher. Using the composite layer, the 'Grid Index Feature' tool was then used to create a grid of cells spanning the entire study area. Each grid cell measured 500 square meters and was labeled with a reference index consisting of a letter (vertical) and number (horizontal) (Black et al. 2015; Martin et al. 2008; Miller er al. 2014) (Figure 9). Finally, the 'Tabulate Intersection' tool was used to calculate the percent area of each fishing polygon within each grid cell.

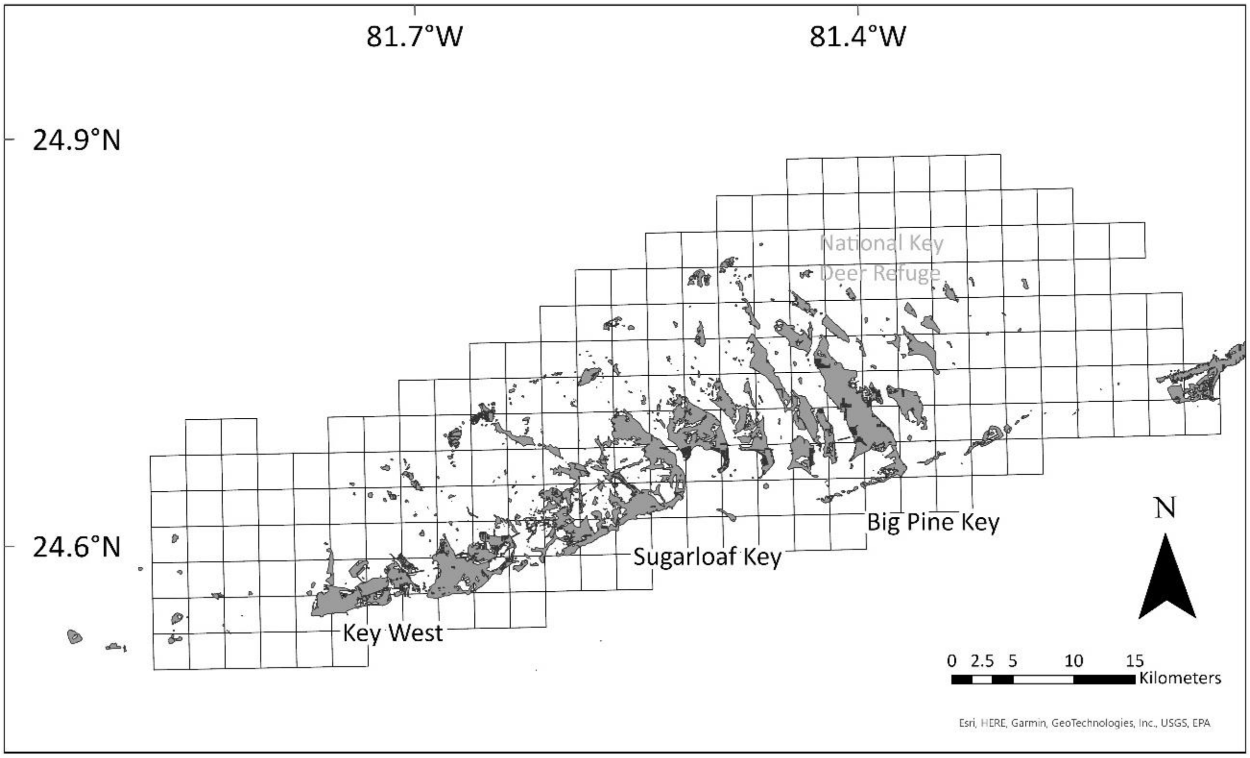

Figure 9: Illustration of static reference grid.

Following Black et al. (2015), 33% fishing usage by area indicates high use and so, any fishing polygon surpassing this threshold in each grid cell was given a score of "1". A score of "0" was assigned to any polygon with an intersecting area of less than 33%. This method proved useful in the removal of outliers in the dataset. Fishing usage percent was calculated as:

Fishing usage (%) = $\frac{Sum\ (usage\ score)}{Cumulative\ Sum} \times 100$ which represents the percentage of fishers who fish in each grid cell. Calculations for cumulative percent were performed in RStudio 1.3.959. Each cell's fishing usage value was then assigned to the coordinates at the center of each grid cell using the 'Feature to Point' tool (Figure 10). Point data was converted into a heat map to show areas of high fishing usage using Ordinary Kriging, a geostatistical technique that assumes the mean is an unknown constant (Esri 2011). This method uses the value of nearby locations to interpolate the value at unobserved locations while attempting to minimize the residual variance and keep the mean residual to zero (Peng et al. 2014) thus every pixel in the study area has been interpolated and assigned a predicted high fishing usage value (Figure 11). A spherical semivariogram model was used to predict the unknown surface based on a theoretical variogram of measured points (Black et al. 2015; Anselin 2005; Esri 2011). Values representing fishing usage were ranked in three usage groups – Low (< 50), Medium (51 – 70), and High (> 71). Due to the abundance of low usage areas, values representing < 30 were omitted from this study.

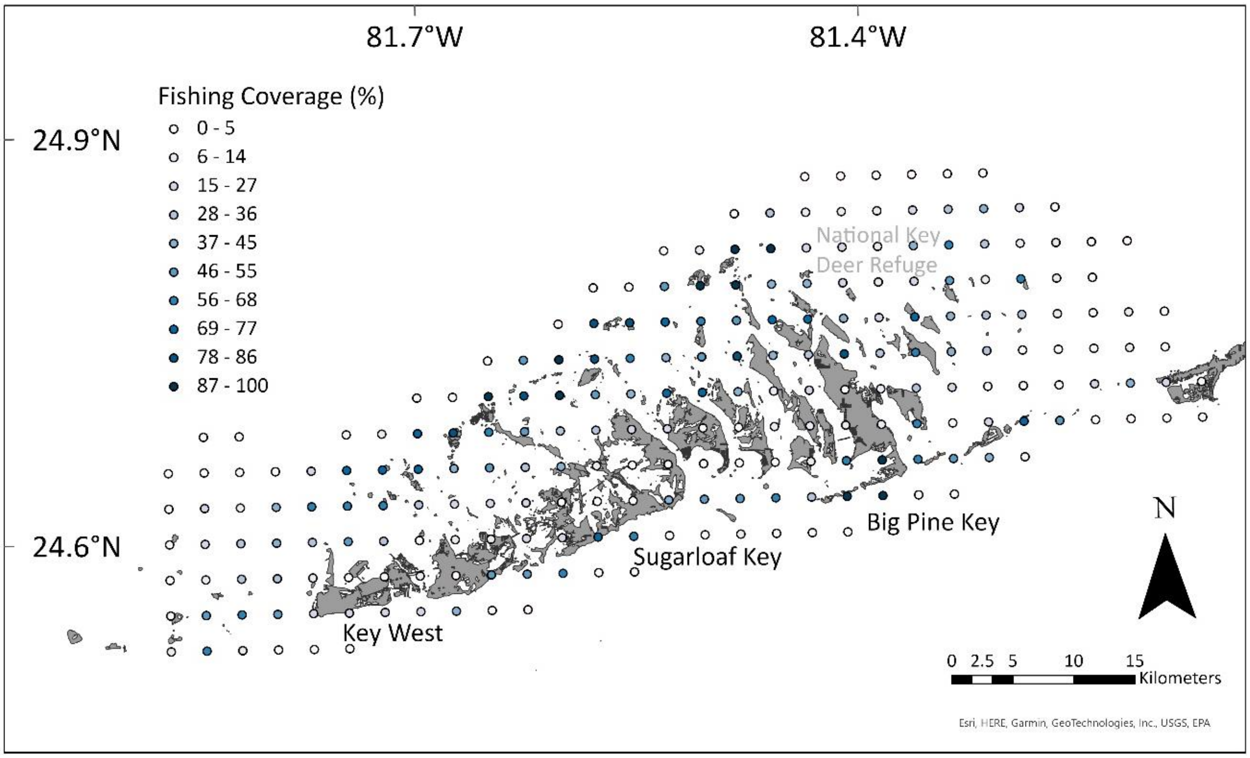

Figure 10: Illustration of point data generated from aggregated fishing coverage (%).

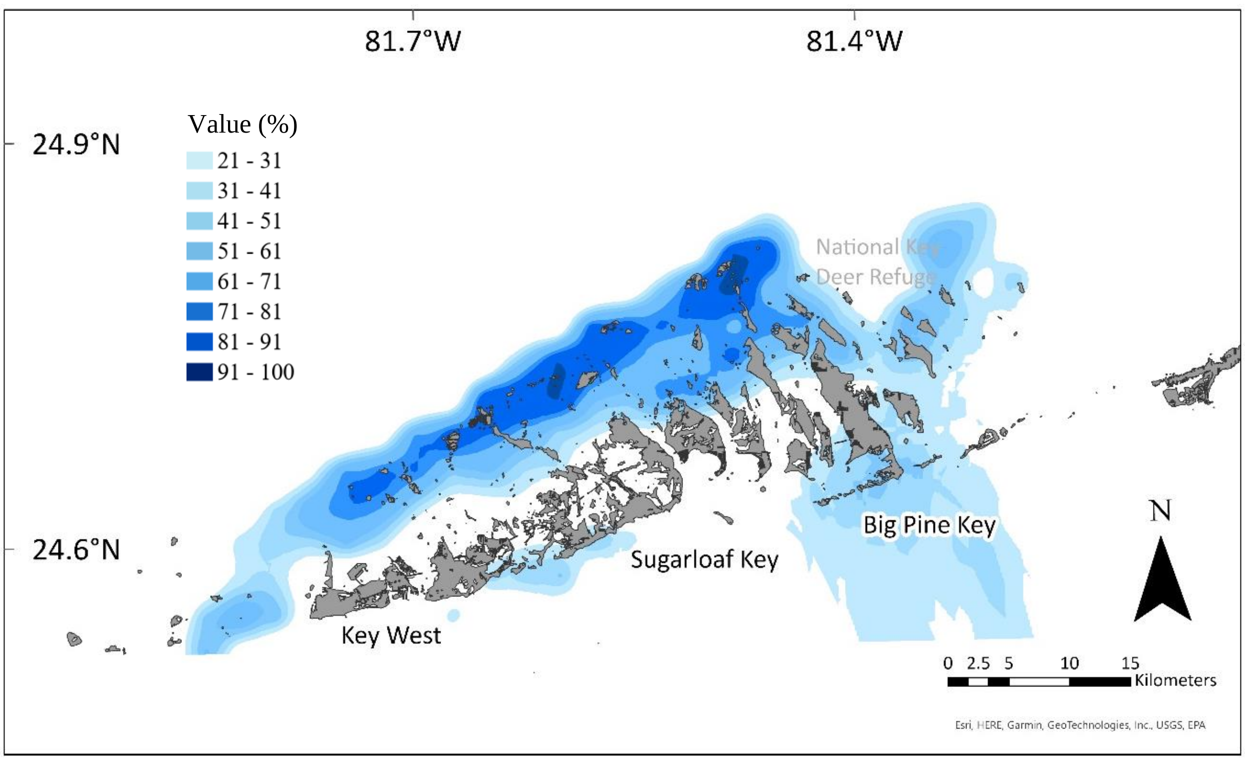

Figure 11: An illustration of Ordinary Kriging fishing coverage map generated from aggregated fishing coverage (%).

In order to analyze the areas of the three fishing usage groups, the heat map was converted into polygons using the ‘Raster to Polygon’ tool which is used to convert an integer raster to a polygon. Because the raster values were of the ‘float’ datatype, the ‘Reclassify’ tool was applied first to change the values within the raster to integers. Polygons were then created based on the three usage groups (low, medium, and high). Once converted, the ‘Calculate Geometry Attributes’ tool was used to estimate the area for each fishing usage group. The ‘Intersect’ tool was used to identify and remove the portions of polygons that overlapped land with the fishing usage areas then recalculated for the remaining polygon features.

2.2 Seagrass Scar Mapping

To assess areas with high fishing usage overlapping those with high seagrass scarring, the fishing usage map was superimposed with a seagrass scarring layer made available from a previous study that assessed boater impacts to the shallow water flats in the FKNMS (Kruer 2017) (Figure 12). Using high resolution (0.5 foot) 2015 NAIP and 2013 NAIP (1.0 meter) color aerial imagery as the digital base, Kruer (2017) mapped the density of seagrass prop scars in the Lower Keys while applying the methods of Sargent et al. (1995). In this study, prop scar polygons were categorized into three distinct scarring intensities – Light (presence of scars in < 5 % of a polygon), Moderate (5 % - 20 %), and Severe (> 20 %). Using these data from the previous study, the ‘Intersect’ tool was used to identify and calculate the area of seagrass polygons that overlapped with the different fishing usage groups. Overlap was then quantified and analyzed using RStudio Version 1.3.959.

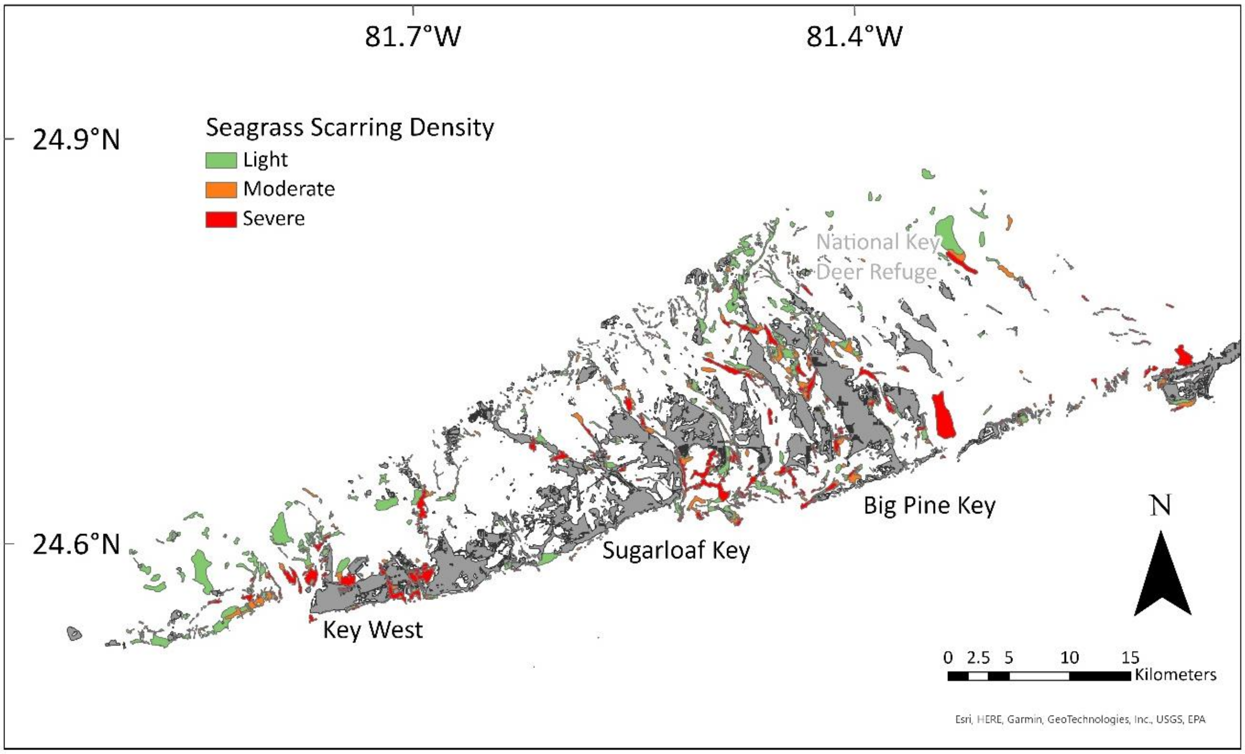

Figure 12: Seagrass scarring layer portraying scar density in the Lower Keys (Kruer 2017).

2.3 Proximity to Boat Ramps

Boat ramp locations were obtained from Florida Fish and Wildlife Conservation Commission. The 'Generate Near Table' tool was used to generate a table containing the distance from seagrass polygons to the nearest boat ramp. The 'Find Only Closest Feature' option was used to prevent multiple calculations from a single seagrass patch (Figure 13). Comparisons between seagrass scarring density and proximity to boat ramps were made using a one-way Analysis of Variance (ANOVA), with seagrass density (Light, Moderate, and Severe) as the factor. Normality was tested using a Shapiro-Wilk test and Bartlett's test was used to test for homogeneity of variances (SAS Institute 1999). In order to meet the above assumptions, a square root transformation on distance was performed. Following the one-way ANOVA, a Tukey's Honest Significant Difference (HSD) test was applied to test the significant difference between factors.

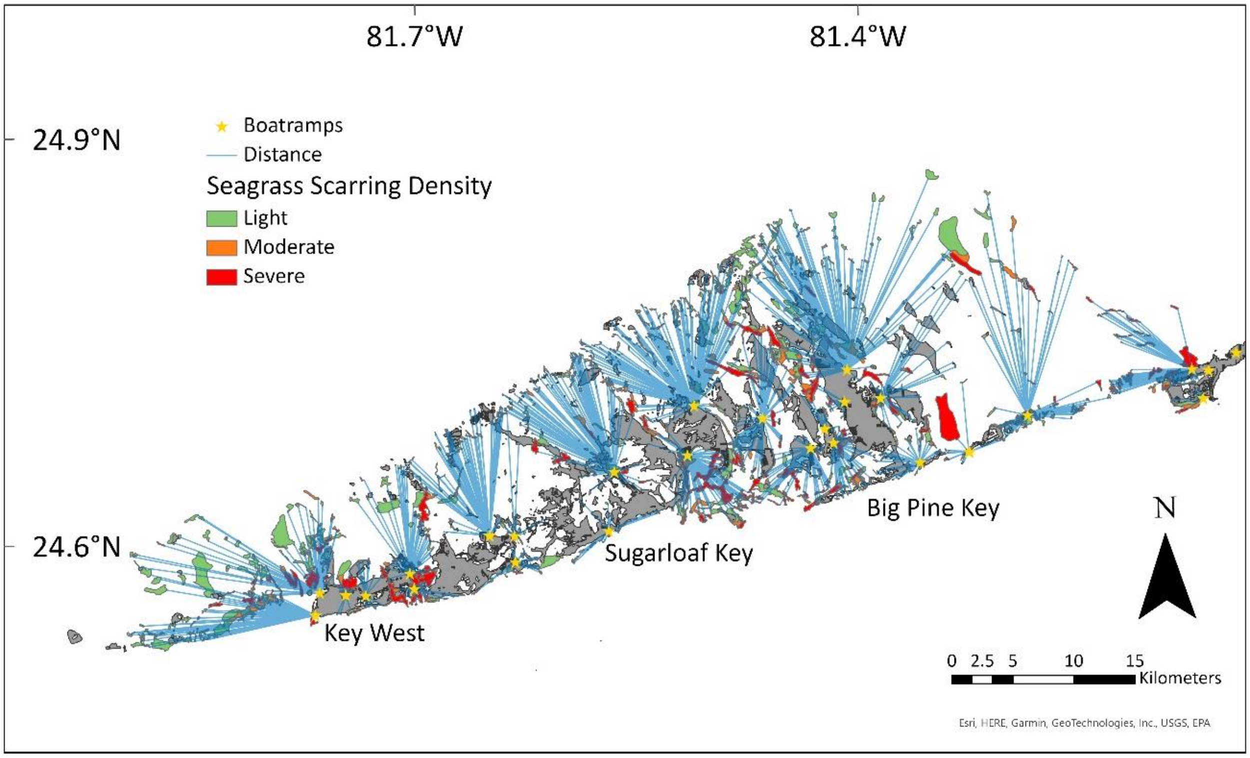

Figure 13: Map illustrating distance calculated from boat ramps to seagrass polygons using the 'Generate Near Table' tool.

2.4 Proximity to Shorelines

A similar procedure was followed to test the relationship between distance from shoreline and seagrass scar polygons. Due to the complexity of the Lower Keys (many small, uninhabited mangrove islands), the aim was to focus on proximity around the more densely populated main islands. Main islands included any U.S. 1 intersected island from Mile 0 in Key West east to the 7 Mile Bridge (Mile 47) (Figure 14). The 'Generate Near Table' tool was used to calculate the distance from the shoreline to seagrass polygons using the 'Find Only Closest Feature' option to prevent multiple calculations to a single polygon (Figure 15). Normality and homogeneity of variances were tested using the Shapiro-Wilk test and a Bartlett's test, respectively (SAS Institute 1999). However, assumptions were not met therefore a non-parametric Kruskal – Wallis test and a Chi-Square test were performed. Following the results, a non-parametric multiple comparisons post-hoc test was used to assess which differences were significant (Benavoli et al. 2016). All calculations and analyses were conducted using the software RStudio 1.3.959.

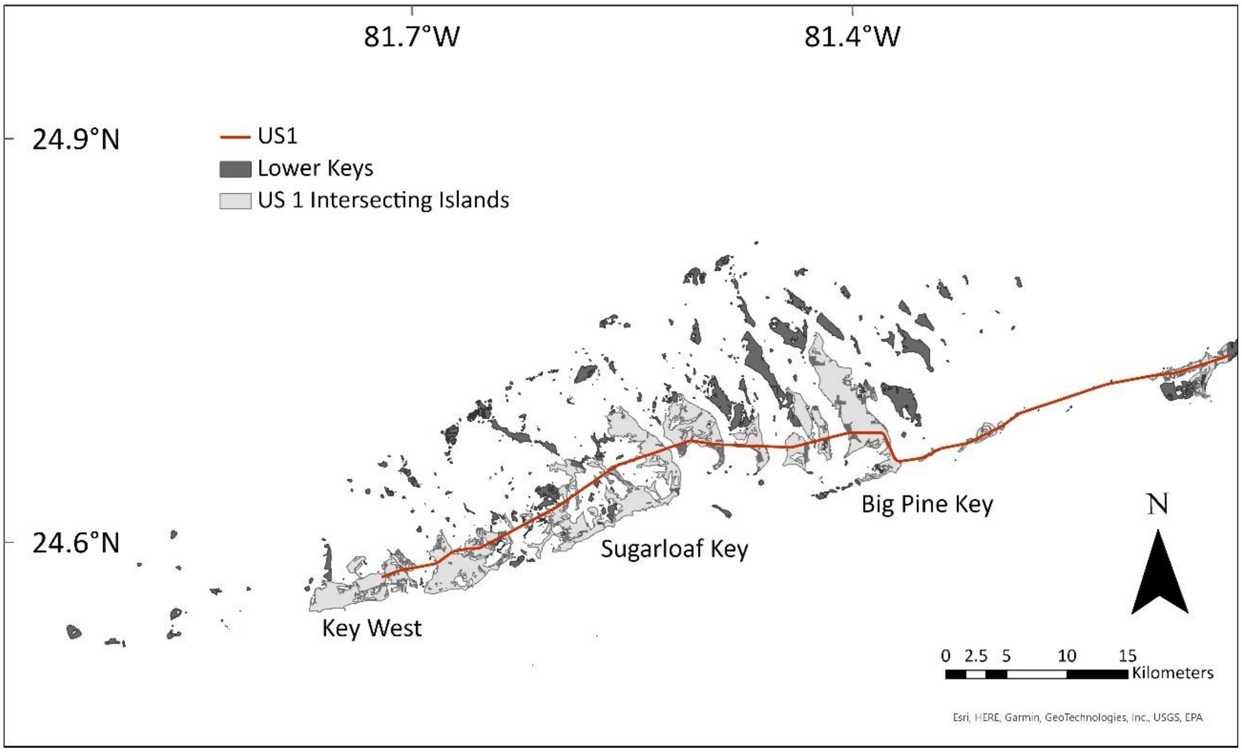

Figure 14: Illustration of U.S. Highway 1 intersecting islands in the Lower Keys.

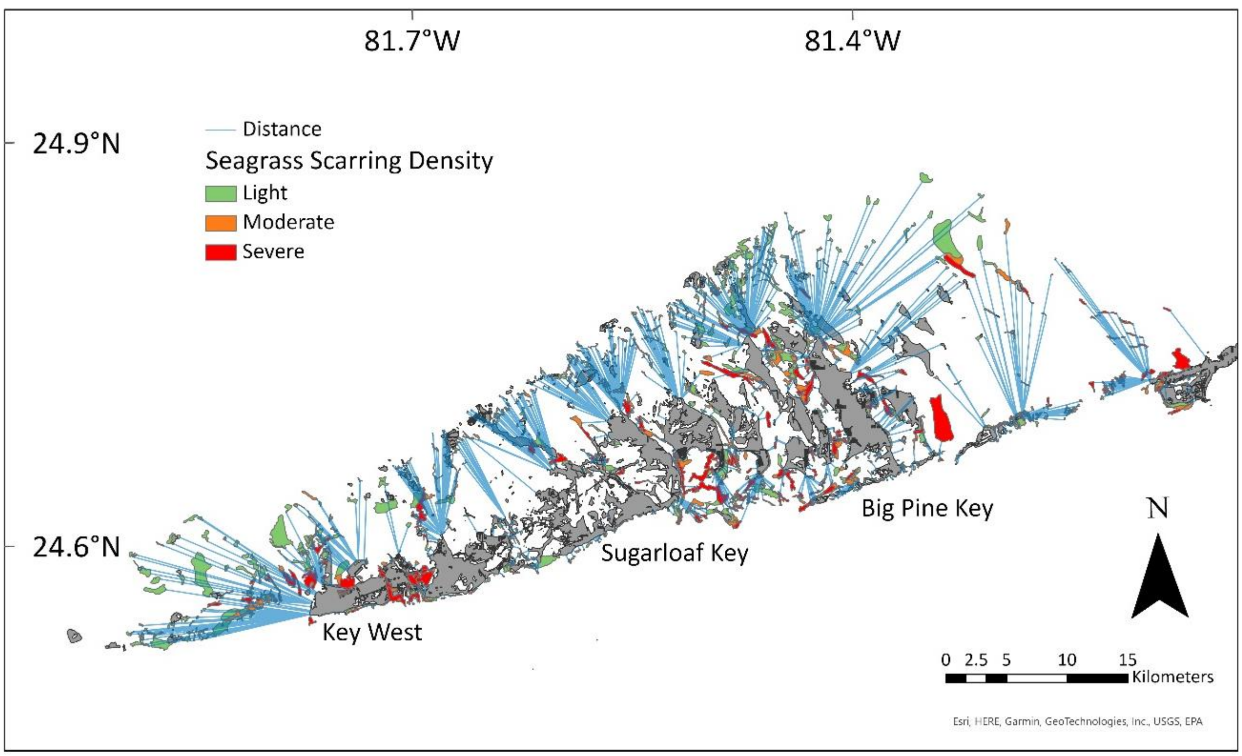

Figure 15: Illustration of distance calculated from the shoreline of US 1 intersecting islands using the 'Generate Near Table' tool.

3.0 Results

A total of 24 maps from fishing guides in the Lower Keys were used to gather spatial data on fishing usage. One individual who provided spatial data felt uncomfortable circling fishing locations south of Sugarloaf Key due to a lack of personal knowledge of the area. Of the 24 participants, 20 participants delineated fishing areas between tarpon, permit, and bonefish. Out of those 20 participants, 13 circled using different colored markers, three highlighted areas using different colored markers, three drew with pencil and one with pen labeling circled areas with "T" (tarpon), "P" (permit), or "B" (bonefish). Two individuals did not distinguish fishing locations between bonefish, tarpon, and permit and two maps represented areas fished only for tarpon.

3.1 Fishing Usage Map Analysis

The aggregated fishing usage map demonstrates that fishing was concentrated in nearshore oceanside habitats and near major channels linking the Atlantic Ocean to the Florida Bay (Figure 11). However, the area with the highest fishing coverage primarily occurred around the bayside mangrove-fringed islands (Coon Key, Water Keys, Big Spanish Key). Moderate fishing usage mainly occurred in nearshore bayside habitats near main islands while some moderate fishing was observed west of Key West. For the majority of the Lower Keys, there was little fishing concentrated near U.S. Highway 1 with the exception of small areas east of Big Pine Key. Due to the sensitive nature of the data, high-resolution spatial data on fishing locations will be discussed with participants and management officials but will not be discussed further in this article.

3.2 Scar Density Analysis

The scar density map suggested that scaring covers a large proportion of shallow water areas close in proximity to channels, shorelines, and the larger islands in the Lower Keys (Key West, Big Pine, Cudjoe Key, and Sugarloaf Key) compared to the bayside mangrove-fringed islands. Overall, there was a greater number of lightly scarred polygons (839) versus moderately scarred (358) and severely scarred (378). Lightly scarred patches also covered the greatest amount of area representing nearly 66,000 km^2, while moderately and severely scarred patches covered approximately 22,000 km^2 and 44,000 km^2, respectively (Table 1). Spatial observations showed that the majority of the severe and moderate scarring was located between Sugarloaf Key and the west end of the 7 Mile Bridge, while light scarring was more evenly spread throughout the entirety of the Lower Keys.

Table 1: Summary of seagrass scarring area calculated from using the 'Raster to Polygon' tool.

Density	Total Area (km^2)	Minimum (km^2)	Maximum (km^2)	Mean (km^2)
Light	65849	2.06	3887	78.5
Moderate	22433	2.06	1031	62.7
Severe	44032	2.08	4144	116.5

Overlaying seagrass scarring data on the fishing usage polygons revealed that at least 11 % of the total fishing usage occurred in scarred seagrass habitat – 7 % in lightly scarred, 2 % in moderately scarred, and 2 % in severely scarred. In areas of high fishing coverage, 14 % occurred in scarred seagrass habitats – 11 % occurred in areas of light scarring, 2 % in areas of moderate scarring, and 1 % in areas of severe scarring (Table 2). Also notable, 76 % of the severe seagrass scars in the high fishing coverage area occurred nearshore and oceanside, while 14 % occurred in the backcountry. In total, approximately 1,200 km^2 of moderate scarring and 6,000 km^2 of light scarring were observed in high fishing coverage areas, whereas nearly 770 km^2 of severe seagrass scarring was observed in areas of high fishing coverage.

Table 2: Summary of the percent overlap between fishing usage and seagrass scar density calculated using the 'Intersect' tool.

Fishing Usage Groups	Light (%)	Moderate (%)	Severe (%)
31 – 40	5	2	3
41 – 50	6	2	3
51 – 60	9	3	1
61 – 70	9	2	1
71 – 80	7	1	1
81 – 90	13	2	1
91 – 100	18	3	0

3.3 Boat Ramp Proximity Analysis

A total of 26 boat ramps and 1,575 seagrass scar patches representing 112,124.61 km^2 (43291.3 mi2) were mapped throughout the Lower Keys. The distance from boat ramps significantly differed between scar severity in the Lower Keys (Df= 2, F = 37.387, $P < 2.2e-16$). The analysis suggests a decrease in scarring density as the distance from boat ramps increase, meaning that severe and moderate scarring is observed closer to boat ramps compared to light scarring (Figure 16). The distance to lightly scarred polygons is significantly different from the distance to moderate and severely scarred polygons ($P < 0.001$) which was not significantly different from each other ($P = 0.081$). For all seagrass patches, the distance from boat ramps ranged from 4.4 m to 18.2 km with a mean distance of 4.7 (S.D ± 3.6) km. Lightly scarred patches ranged from 97.9 m to 18.2 km with a mean distance of 5.5 (S.D ± 3.8) km, moderately scarred patches ranged from 12.2 m to 15.1 km, with a mean distance of 4.2 (S.D ± 3.3) km, and severe patches ranged from 4.4 m to 15 km with a mean distance of 3.6 (S.D ± 3) km (Table 3).

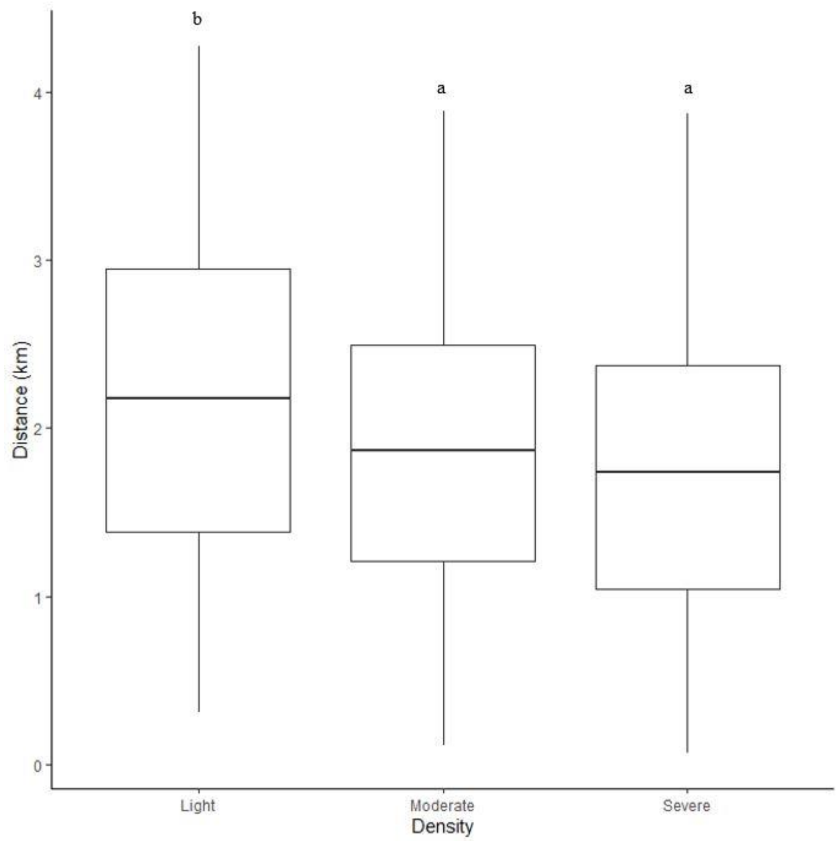

Figure 16: Boxplot of scar density distance from boat ramps. Bars represent standard deviation. Letters stand for significant differences between scar density ($p < 0.05$). Tukey's test showed that light scarring (b) is significantly different from moderate scarring (a) and severe scarring (a). A square root transformation on distance was performed.

Table 3: Summary of the distance from boat ramps to scar density polygons.

Density	Minimum (m)	Maximum (km)	Mean (km)	Standard Deviation
Light	97.93	18.24	5.46	3.82
Moderate	12.30	15.11	4.17	3.82
Severe	4.40	14.96	3.65	3.00
Total	4.40	18.25	4.74	3.61

3.4 U.S. Highway 1 Proximity Analysis

U.S Highway 1-intersecting islands included Key West, Stock Island, Boca Chica, Big Coppitt Key, the Sugarloaf Keys, Cudjoe Key, Summerland Key, Ramrod Key, Little Torch Key, Middle Torch Key, Big Pine Key and Bahia Honda Key. Distance from the shoreline of these islands significantly differed between scar severity (Chi-squared = 49.604, df = 2, P = 1.693e-11) which suggests severe and moderate scarring was observed closer to the shoreline of these islands compared to light scarring. The non-parametric multiple comparisons post-hoc test suggested light scarring was significantly different from severe and moderate scarring (Figure 17). For all seagrass patches, the distance from the shoreline ranged from 0.1 m to 17.64 km with a mean distance of 3.03 (S.D ± 3.36) km. Lightly scarred patches ranged from 0.2 m to 17.63 km with a mean distance of 3.86 (S.D ± 3.64) km, moderately scarred patches ranged from 0.4 m to 15.06 km with a mean distance of 2.67 (S.D ± 2.95) km, and severe patches ranged from 0.11 m to 15.57 km with a mean distance of 2.26 (S.D ± 2.73) km (Table 4).

Table 4: Summary of the distance from main islands to scar density polygons.

Density	Minimum (m)	Maximum (km)	Mean (km)	Standard Deviation
Light	0.2	17.63	3.86	3.64
Moderate	0.4	15.06	2.67	2.95
Severe	0.1	14.57	2.26	2.73
Total	0.1	17.63	3.03	3.36

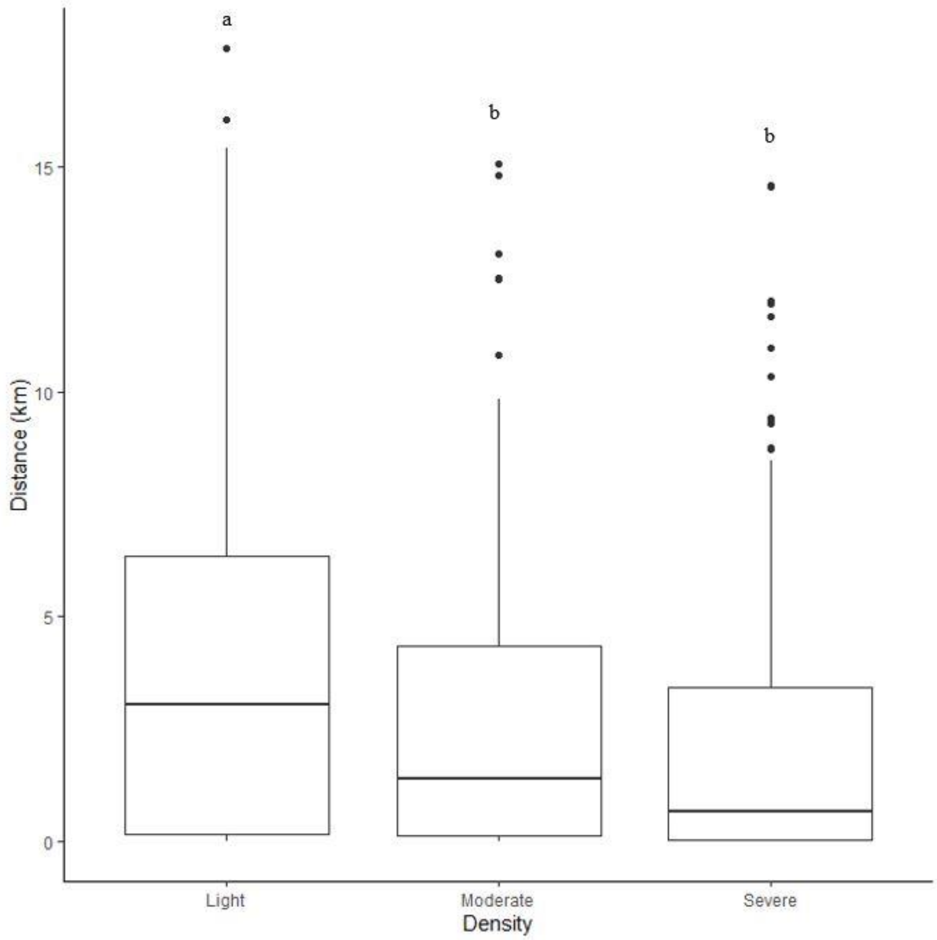

Figure 17: Boxplot of scar density distance from main islands. Bars represent standard deviation. Letters stand for significant differences between scar density ($p < 0.05$). Tukey's test showed that light scarring (a) is significantly different from moderate scarring (b) and severe scarring b).

4.0 Discussion

As human populations continue to increase in coastal areas, the associated negative impacts, such as habitat destruction, are not likely to be resolved without conservation practices. In areas such as the Florida Keys, where the flats fishery is culturally and economically valuable, it is imperative to understand the individual and interactive effects of anthropogenic activities on the fishery. This study quantifies usage areas of the flats fishery by integrating the ecological knowledge of local stakeholders which can be used to develop management plans to promote the sustainability of the fishery's resources. Local recreational fishing guides are an ideal source of information given their frequent interactions with their targeted species and the surrounding environments (Gervasi et al. 2022). The use of local ecological knowledge held by fishers about fishing resources has the potential to improve fishery management by providing a unique approach to a more collaborative and actionable science (Silvano and Valbo-Jørgensen 2008; Feng et al. 2020; Gervasi et al. 2022b).

One of the great challenges to conserving and managing bonefish, tarpon, and permit is the lack of species stock assessment data, knowledge of migration patterns and spawning locations, and fishery information such as location and landing data. Even though there has been a recent increase in research assessing these issues (Adams et al. 2019; Adams and Cooke 2015; Brownscombe et al. 2020; Drymon et al. 2021; Adams et al. 2006; Adams and Blewett 2004; Crabtree et al. 2002; Holder et al. 2020), there is still a lack of understanding fishing effort in the flats fishery. Spatial effort data is challenging to obtain because anglers often mistrust management agencies and do not readily release proprietary fishing records of personal fishing locations (McCluskey and Lewison 2008; Black et al. 2015). However, with careful relationship building and mutual trust among partners, it is possible to obtain fishery-specific data from local stakeholders (Pomeroy and Douvere 2008; Black et al. 2015; Granek et al. 2008; Nutters and Pinto da Silva 2012; Macher et al. 2018). The trust between partners and the inclusion of these data ensures the long-term conservation and sustainability of a healthy flats fishery in the FKNMS.

4.1 Fishing Usage

Overall, bayside mangrove-infringed islands had a lower density of seagrass scarring and the highest fishing concentration compared to habitats near the main islands. Black et al. (2018) found similar trends and concluded that 94% of flats fishing occurred in seagrass habitats. Since bonefish, tarpon, and permit rely on the complexity of seagrass habitats, these findings were not unexpected and suggest that these species are more concentrated near the mangrove-infringed islands where seagrass is the dominant habitat type. Nevertheless, multiple ecological and anthropogenic factors are likely causing anglers to focus their fishing efforts in these areas.

First, the structural complexity of seagrasses provides essential nursery habitats for a high diversity of juvenile fishes by offering shelter against larger predators (Nagelkerken et al. 2001; Orth et al. 2006; Adams and Blewett 2004). Multiple studies also suggest that juvenile fish, crustaceans, and invertebrates have a higher growth rate in seagrass meadows compared to other habitats (Jr et al. 2003; Malloy et al. 1996; Rooker et al. 1997; Stoner et al. 1996). Since bonefish, tarpon, and permit feed on small fish, crustaceans, and invertebrates, seagrass flats provide ideal foraging grounds (Perez et al. 2019; Adams and Cooke 2015; Adams and Blewett 2004).

Previous studies have also suggested that the density and diversity of invertebrates and fishes are more significant in seagrass habitats compared to bare substrates (Arrivillaga and Baltz 1999; Adams et al. 2016; Duffy 2006; Orth et al. 2006). The direct loss of habitat that occurs from a scarring event has led to the assumption that this type of disturbance has a detrimental effect on seagrass communities (Bell et al. 2002; Uhrin and Holmquist 2003; Sargent et al. 1995). Although bonefish, tarpon, and permit have been observed using scars as alleys to forage (Uhrin and Holmquist 2003; Bell et al. 2002), Uhrin and Holmquist (2003) also showed that bare sand trenches created by propeller scarring contained fewer total macrofauna and invertebrate prey compared to adjacent seagrass communities. Since propeller scarring removes both habitat and shelter, smaller invertebrates and crustaceans most likely relocated to seagrass healthy seagrass (Uhrin and Holmquist 2003), causing predators such as bonefish, tarpon, and permit to follow.

With the Florida Keys being a popular vacation destination for recreational boaters, noise pollution can also be a serious threat to fish in the area. Multiple studies have suggested that boat noise from a combustion engine negatively impacts fishes' health, communication, and behavior (Codarin et al. 2009; Amoser, Wysocki, and Ladich 2004; Mitson and Knudsen 2003; Scholik and Yan 2002; Wysocki, Dittami, and Ladich 2006). Matthew et al. (2018) found in the Lower Keys there was a higher density of boaters oceanside and near the main islands compared to the backcountry. Thus, species such as bonefish, tarpon, and permit may be avoiding these highly trafficked nearshore areas and seeking refuge around the bayside mangrove-infringed islands where there are fewer disturbances. However, further analysis would be necessary to understand the effect of acoustic stress on the flats fishery.

Finally, local recreational fishing guides have a vested interest in providing visitors with a high-quality experience. When fishing for bonefish, tarpon, and permit, most anglers are more motivated by the thrills and challenges rather than the harvest. Guides likely frequent areas where they know they will be successful in catching their target species and that provide their customers with the natural experience they seek. Indeed, the highest fishing concentration in this study was observed further from the densely populated main islands of the Florida Keys and closer to small, uninhabited mangrove islands and such areas provide a unique natural experience to customers who may be accustomed to city life. Customer satisfaction can be affected by aesthetics and fishing success (SFNRC 2008) and therefore, guides may be avoiding densely scarred seagrass flats because customer experiences will likely be negatively impacted.

4.2 Seagrass Proximity to the Main Islands

Most of the densely scarred seagrass patches were concentrated near the main islands of the Lower Keys. These findings are important because they may indicate that the local recreational fishing guides who frequent the bayside mangrove-infringed islands are experienced in maneuvering shallow water flats. Guides often take environmental precautions while fishing because they have a vested interest in the sustainability of the flats fishery. Guides typically use flats boats, commonly known as "skiffs", which have a shallower draft (< 15 cm) than an offshore fishing vessel or bay boat (> 25 cm), allowing guides to fish on shallow seagrass flats. Also, guides typically use a long (20 ft) pole to push the boat across the flats (known as push-poling) which does not require the use of combustion engines in shallow water seagrass habitats.

Visitors may also be avoiding the complex and shallow water areas of the Lower Keys because of a lack of experience or the reduced maneuverability of larger vessels in the area. The Lower Keys are challenging to navigate and therefore, new, and inexperienced users are likely to avoid these areas that are not clearly marked (Sargent et al. 1995). Although there was no significant difference when examining seagrass scars in proximity to marked and unmarked channels in the Everglades National Park, Barry et al. (2020) found that navigational aids resulted in immediate and direct increase in seagrass-friendly boating by boated slowing their approach and trimming the motor. The lack of difference in the Everglades National Park may have resulted from the more intensive use of marked channels versus unmarked channels (SFNRC 2008). Unmarked channels are also likely to be used less intensely and most often by resident boaters and local recreational fishing guides who have substantial experience navigating the area. In contrast, inexperienced boaters unfamiliar with the location of channels and often lacking navigational charts may avoid such areas (Sargent et al. 1995).

With 28,895 registered vessels in Monroe County (FLHSMV 2020) alone, and thousands of visiting boaters throughout the year, the marine resources in the FKNMS are heavily impacted. For example, a prior study found that most boating activity (Matthew et al. 2018) and related damage to seagrass habitat is concentrated near the main islands of the Lower Keys. On average, Matthew et al. (2018) observed 1,796 ± 1,047 boats per typical day, while holiday weekends averaged 2,875 ± 818 boats per day. Boaters misjudging water depth and accidentally scar seagrass beds, boaters intentionally leaving marked channels to take shortcuts across shallow water seagrass flats, and boaters lacking navigational charts and carelessly navigating in shallow seagrass beds are all thought to be possible causes for these damages (Sargent et al. 1995; Woodburn et al. 1957; Godcharles 1971; Eleuterius 1987; Zieman and Zieman 1989). Notably, the number of vessels registered in a county is not always a predictor of seagrass scarring in that county (Sargent et al. 1995). For example, Sargent et al. (1995) found that Broward County had 42,612 registered vessels and less than 20 acres of scarring. In contrast, Monroe County had 20,163 vessels registered but contains the greatest acreage of seagrass scarring in the state (Sargent et al. 1995). Therefore, while we attribute some of the impacts found in this study to recreational boater damage, further studies are needed to understand the relative contribution of recreational boater use to scarring density and pattern in the FKNMS.

4.3 Seagrass Proximity to Boat Ramps

As the Florida Keys boater population continues to increase, threats to valuable habitats including seagrass communities increase. With many boaters bringing personal boats to the Florida Keys, public boat ramps are one of the most heavily trafficked assess points. The strong relationship between scarring and proximity to boat ramps suggests that many users accessing the FKNMS through boat ramps lack the necessary experience and knowledge to avoid damaging the surrounding habitats. Evidence suggests that more experienced boaters tend to better understand the ecological consequences of seagrass scarring than less experienced boaters (Barry et al. 2020). Thus, residents who have experience with the complexity of the Lower Keys are likely to cause less damage to the surrounding habitats than visitors. These findings are important because resource managers could focus on strategies that educate visitors on the importance of safe boating around seagrass flats. Barry et al. (2020) focused on comparing the knowledge of seagrass and seagrass scarring from participants who were randomly approached at boat ramps. Results showed that many boaters admitted to causing seagrass scarring, but few reported that seagrass scarring was an issue (Barry et al. 2020). An important educational message is communicating the need to limit the size, draft, and power of vessels in shallow water seagrass habitats as scarring mainly occurs in less than one meter (SFNRC 2008). Thus, including educational messages via boater safety classes, handouts, and information at boat rental companies and hotels may increase effectiveness and efficiency in reducing propeller scarring by visitors.

A single management approach, such as education alone, only partially addresses the problem of seagrass scarring (Sargent et al. 1995). Propeller scarring in the FKNMS should be viewed as destruction of publicly protected marine resources. Therefore, federal and state management officials should consider raising the penalty for vessel damage to benthic communities. Increasing the cost of each offense not only incentivizes enforcement agencies to enforce the rules and regulations through a higher revenue generation potential but also impresses upon visitors a monetary importance of the resource to the local community. Resource managers could also focus on strategies that manage navigation and access of motorized vessels around boat ramps by including the use of navigational aids such as buoys, channel markers, and signs near boat ramps. Buoys should be clearly visible and permanent, bearing the message “CAUTION SEAGRASS AREA” or “SHALLOW AREA” and placed well beyond the edges of the flats to provide a wide enough buffer ensuring protection against scarring which will benefit all boaters by establishing the correct passage to and from boat ramps. Such modifications to management strategies designed for specific areas will reduce seagrass scarring, over the long term, to levels that do not significantly affect marine use or habitat quality.

4.4 Study Challenges

This study provides evidence that local ecological knowledge can be used for the management of recreational fisheries by relying on the willingness and ability of local stakeholders. However, despite increasing usage and acceptance, using stakeholder knowledge suffers from continued challenges and biases (Gervasi et al. 2022). For example, fishing locations may reflect the ephemeral and seasonal distribution of targeted species (McCluskey and Lewison 2008) given that the regional distribution of some target species such as tarpon have been known to migrate over thousands of kilometers throughout the year (Luo et al. 2020). Another challenge is a small sample size of willing participants. In Black et al. (2018), 127 full-time fishing guides were contacted throughout the Florida Keys and only 45 provided data – 24 being in the Lower Keys and that were used in this study. This small sample size could lead to an incomplete picture of actual fishing usage and a biased view of the flats fishery as a whole.

The potential for exaggeration on fishing usage, unwillingness to include certain fishing spots (i.e., areas with a high catch rate), participant memory, and distance traveled by guides may also influence the study results. A limitation specific to recreational stakeholder knowledge is that the data's accuracy depends upon angler recall and willingness to report everything (Gervasi et al. 2022). Also, human perception and memory are subject to an individual's experience (Pauly 1995) therefore, the accuracy of spatial data may vary depending on age and experience level. Other studies have also suggested that older or more experienced stakeholders were more likely to report changes in abundance over time than younger or less experienced stakeholders (Gervasi et al. 2022; Beaudreau and Levin 2014; Frezza and Clem 2015).

Finally, the seagrass scar map produced by Kruer (2017) and used in this study is a conservative estimate and does not represent the full extent of boater impacts in the Florida Keys as only visible scars were mapped, and many questionable areas (typically from the intertidal zone to about 2 meters deep) were not included. Boater impacts can also independently or synergistically act with other sources of environmental stress, such as a decrease in water quality, leading to a further decline in seagrass coverage (Bell et al. 2002; Orth and Moore 1983, Fortes 1988, Preen et al. 1995) which causes challenges in developing definitive conclusions related to trends in prop scarring for the surrounding area. However, mapping seagrass scars can describe patterns of scarring density as they relate to marine resource use and be useful in selecting regions where management can focus on improving resources and visitor use conditions. Results from Kruer (2017) showed a significant increase in the extent and severity of propeller scars compared to maps in the mid-1990s. Therefore, it is reasonable to conclude that seagrass scarring has not improved and has likely worsened due to the increase in south Florida's population and boat traffic. Prop scarring is likely to remain a prominent concern unlikely to improve without new management strategies for the FKNMS.

4.5 Florida Keys National Marine Sanctuary's Proposed Management Plan

Marine management raises several societal issues, including the political acceptability of the marine reserve concept, the social/economic groups that will stand to gain or lose as a result of reserve creation, and the perceptions and opinions that group members possess about the marine reserve (Suman et al. 1999). For the flats fishery, many anglers oppose some FKNMS Restoration Blueprint regulations because they feel it imposes needless angling-related restrictions that provide no benefits to the conservation of the flats fishery (BTT 2019). For example, Bonefish & Tarpon Trust strongly opposes Wildlife Management Areas (WMAs) as there is no research demonstrating that flats fishing (push poling or the use of a trolling motor) has adverse impacts on wildlife and habitats that these WMAs are meant to protect (BTT 2019). Also, complete closure zones negatively impact the local recreational fishing guide businesses and others that rely on the availability of the local resources (Black et al. 2015; Read et al. 2011; Miller et al. 2014). In contrast, Bonefish Tarpon & Trust supports several regulations, including the expansion of existing idle speed/no wake zones along residential shorelines to include 100 yards of all shorelines, the prohibition of discharge of any material or other matter from cruise ships (excluding clean vessel engine cooling water, clean vessel generator cooling water, vessel engine or generator exhaust gas, clean bilge water, or clean anchor wash water), and the inclusion of Pole/Troll and Idle Speed zones (BTT 2019). These restrictions in theory will alleviate stress from propeller scarring and water quality on important shallow water habitats throughout the FKNMS, allowing for the habitats to recover and better support the flats fishery.

4.6 Future Work

Overall, the FKNMS Restoration Blueprint in its current state is insufficient for protecting flats habitats that support the fishery and changes are needed to assure the conservation of important shallow water habitats for bonefish, permit, and tarpon. The information provided from this study can be used to provide thoughtful science-based recommendations with the engagement of both local stakeholders and managers. In response to the Restoration Blueprint, the Lower Keys Guide Association recommended management zoning strategies based on the expertise of over 180 local fishing guides identifying areas that are critical to the sustainability of the flats fishery. Comparisons between the Lower Keys Guide Association recommendations and information from this study will be provided to the FKNMS staff to prioritize the locations of management zones. As the revisions for the Restoration Blueprint continue, there is ample opportunity to provide the information from this study through the FKNMS public comment. With the cooperation and collaboration of managers, stakeholders, and scientists, we can ensure that our revisions are focused on protecting the flats fishery and the surrounding habitats from existing and future stressors.

5.0 Conclusion

The Florida Keys Ecosystem has gone through considerable environmental changes over the last 20 years and the Florida Keys flats fishery depends on the health and vitality of shallow seagrass beds (Sargent et al. 1995). Nevertheless, preventing all seagrass scarring is impossible as all user-groups scar seagrasses to some degree. Still, we suggest that pole/troll and idle speed zones should be introduced to areas where fishing concentration and scar density is high as demonstrated in this study to allow for the responsible use of these fishing areas by both resident anglers and visitors. The introduction of these management zones would improve the economic potential of our marine environment while achieving the FKNMS's conservation goals. Also, implementing navigational aids near boat ramps and around the shallow water flats near the main islands where scaring density is high will lessen boaters' impact on the flats fishery. By focusing strategies on implementing management zones in these areas, we can help to ensure the longevity and productivity of the flats fishery. If the FKNMS protects the habitats that support the flats fishery, numerous other benefits are achieved including the protection of dozens of other species, such as juvenile snappers, juvenile sharks, stone crabs, lobsters, pink shrimp, wading birds, and rays. In a sense, bonefish, tarpon, and permit can be used as umbrella species, whereby protection of their habitats also protects the habitats of many other economically important species.

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