Feasibility Assessment of Special Management Areas to Enhance Recreational Fisheries and Habitat

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Feasibility Assessment of Special Management Areas to Enhance Recreational Fisheries and Habitat

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Summary

- Stakeholders are concerned about propeller scarring, a local and statewide issue in Florida
- Mapping revealed uneven distribution of propeller scars throughout the study area, with areas of severe scarring concentrated around certain keys.
- In addition to propeller scars in seagrass habitat, our high-resolution mapping efforts also uncovered evidence of disturbances to hardbottom habitats (sponge, coral, and attached macroalgae beds) generated by outboard motors/propellers. We also observed evidence of propeller contact with seagrass leaves with no apparent contact with underlying sediment.
- State agencies have policy options to address propeller scarring through spatial management of boating access, with FDEP having the most statutory responsibility and flexibility (options).
- Fisheries management decisions often have unpredictable outcomes in terms of fishing effort and angler perceptions, and often the initial effects are dampened over time through feedbacks in the system.
- Research in other systems shows that marine reserves, even relatively small ones, can have positive outcomes for fish populations (e.g., increase in average size), especially for fish species with small home ranges.
- More research is needed before it would be possible to predict the outcome of spatial management zones such as pole-and-troll areas, and any management actions that may be put in place should be evaluated pre- and post-implementation to provide insights into socioeconomic and biological (fish, habitat) outcomes.

Introduction

Nearshore recreational fisheries provide tremendous value to the Florida economy. These fisheries are dependent on the availability of high-quality habitat, and sound fisheries management. Habitat can be degraded by several factors, including damage to seagrass flats by propellers of power boats operating in shallow waters (prop scarring). The current fisheries management framework employs regulations limiting harvest by season, fish length, and bag limit (number of fish harvestable per angler per day). Regulations often vary due to regional differences in fishery stocks and population dynamics.

The Homosassa and Crystal River areas have long been key for inshore recreational fishing. Renowned for shallow, clear water, and verdant seagrass flats, the area has long provided world-class sight fishing opportunities to anglers. The fishing opportunities are especially important for supporting for-hire fishing captains who guide clients through these flats in pursuit of redfish, seatrout, tarpon, and, increasingly, snook. Thus, recreational fishing by locals and visitors alike is recognized as an important sector of the local and regional economy. But recent increases in fishing effort and boat traffic threaten to upset this socioecological system. The long-term socioeconomic, ecological, and environmental sustainability of this system requires management actions that preserve habitat and sustain fish populations.

In 2019, stakeholder groups reached out to UF/IFAS and Florida Sea Grant to express concern over the growing issue of prop scarring caused by increased boating around the St. Martin's Keys located in the St. Martins Aquatic Preserve (SMMAP, Figure 1). Stakeholders also expressed interest in exploring the potential for alternative management approaches to address their concerns. Innovative management could include spatially limited areas where strategies such as pole and troll zones or trophy fishing areas, approaches employed elsewhere in Florida, could be implemented.

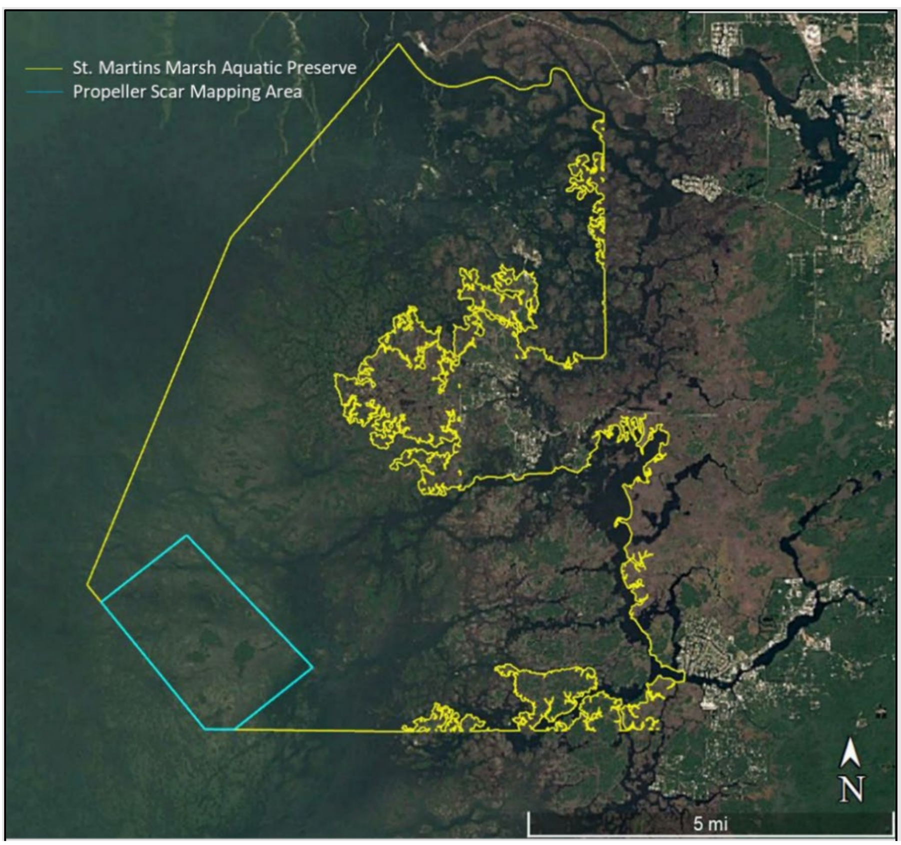

Figure 1. *Propeller scar mapping area within the St. Martins Marsh Aquatic Preserve.*

An initial examination of fishing trends in the Citrus County area provides support for stakeholder concerns. Preliminary analyses of publicly available recreational fisheries data show that inshore boating trips have increased noticeably for the Citrus County area, while the broader Big Bend region shows no clear temporal trend (Figure 2).

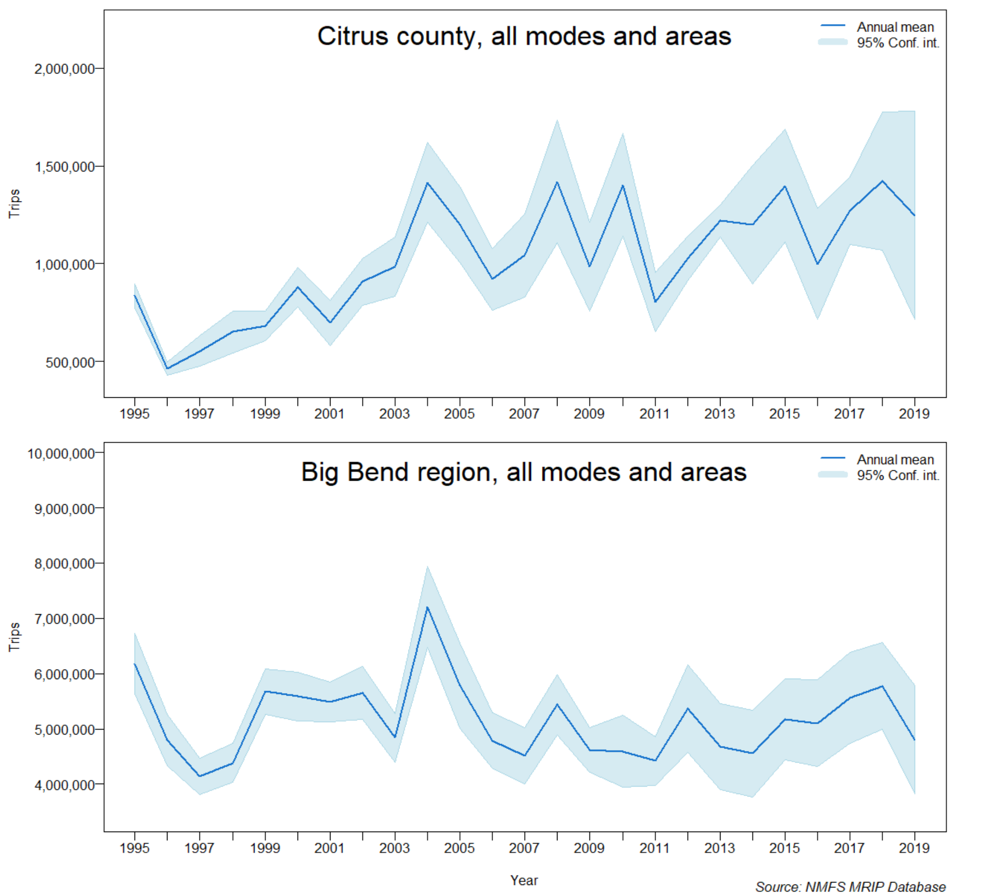

Figure 2. *Time series showing mean number of fishing trips taken in Citrus County (top) and the Big Bend region (bottom). Blue shaded areas represent the 95% confidence interval. Data: NOAA NMFS.*

While this does not provide direct evidence that prop scarring is increasing in the St. Martin's Keys area, it provides support for the idea that boating and fishing activity, and therefore risk of prop scarring (habitat damage), has increased. Furthermore, angler behavior research indicates that most inshore saltwater fishing trips originate from areas nearby (Camp et al., 2018) and population in Citrus County and surrounding areas is up between 6.0 and 23.6% since 2010 (US Census Bureau, 2019). Furthermore, past research in the area has indicated that educational and informational approaches to preventing propeller scarring have only modest positive outcomes on boater behavior (Barry et al., 2020). These results highlight the growing need to consider innovative management of seagrass as fishery habitat and improvements of fishing quality in Citrus County, as these resources are experiencing unprecedented levels of fishing and boating pressure. The SMMAP Management Plan states that *"management emphasis is placed on preventing new damage to resources that may occur with increased use and development"*, a management need that clearly aligns with the goals of this feasibility study.

Our team's overall goal in undertaking this work was to assess the feasibility of creating special fisheries and habitat management areas by completing a holistic review of the relevant biological, socioeconomic, and legal aspects of such areas, using Citrus County as a model. In this report, we will detail findings related to 1) status of propeller scarring in the St. Martins Keys area, 2) legal analysis of options for seagrass protection and special fisheries management areas, 3) possible effects of management actions on fisheries, including a comparative analysis of existing relevant spatial management.

Part 1: Status of Propeller Scarring in the St. Martins Keys

To provide an up-to-date picture of the status of propeller scarring, we conducted propeller scar mapping within a ~2400-acre area in the southwestern region of the St. Martins Marsh Aquatic Preserve (Figure 1) that encompasses the St. Martins Keys. Details about methodology used in capturing and interpreting imagery can be found in Appendices A and B of this report. Briefly, a DJI Matrice 200 V1 unmanned aerial vehicle was used to conduct high resolution mapping flights over a 2.5-week period from 4/22-5/9/2021. The resulting imagery was post-processed and interpreted by trained observers to produce a dataset detailing the location, length, width, and densities of four types of propeller scars (Table 1). "Light scars" can be considered the traditional type of scar most pictured when using the term "propeller scar". However, the other three types of scars (dark scars, hardbottom scars, and airboat scars) also represent evidence of undesirable interactions between vessels and bottom habitats. Therefore, these four scar types were analyzed separately to yield insights about occurrence and severity of impacts to different bottom types.

In all, 24 keys were included in the mapping area and each key was analyzed for scarring density within buffer zones ranging from 100 to 1000-ft from the perimeter of each key (Figures 3, 4). In general, propeller scarring was present throughout the mapped area, with more than 256,000 linear feet of light scars identified and an additional 109,500 linear feet of other scar types, mostly dark scars in seagrass (Table 2, Figure 5). The vast majority of scars identified can be attributed to outboard motors while a minimal number of scars derived from airboat activity (Table 2). Prop scars cover a total of approximately 10.75 acres of marine habitat (seagrass and hardbottom) within the mapped area, 7.2 acres of which are light scars in seagrass (Table 2). The restoration cost for light scars varies widely, with factors such as scar width and depth, boating access points, and inclusion of plantings affecting the per-linear-foot cost. A nearby restoration project around Sandy Hook Key and Fish Creek completed in 2018 had an average light scar restoration cost of $20/linear foot (J. Patterson, pers. comm.). In the Florida Keys National Marine Sanctuary, seagrass restoration is valued at $50/square foot (Ankersen and DePaolis, 2021). Using these estimates, the amount of light scars in the mapped area would cost between $5.1 and $15.6 million to restore (Table 2). Furthermore, the environmental services (e.g., fish production, carbon capture, nutrient storage) lost from the acreage impacted due to light scarring alone is in excess of $83,000/year within the mapped area (Costanza et al., 2014). A recent study highlights that past valuation attempts vastly underestimate the true value of seagrass ecosystem services (Dewsbury et al., 2016), therefore $83,000/yr is a very conservative estimate of the value of functions lost. Furthermore, we cannot estimate the costs to restore or value environmental services lost for dark scars or hardbottom scars due to lack of information about these scar types. Thus, overall, our estimates are quite conservative relative to the total ecological costs of scarring to the St. Martins Keys system. The stakeholder concern that propeller scarring within the St. Martins Keys has become a significant issue is supported by these findings. Special management actions may be justified based on the ecological impacts documented in the mapping effort.

The spatial distribution of propeller scarring is uneven across the study area, with keys 1 and 2 clearly experiencing higher levels of scarring than areas around other keys (Figures 6, 7, 8, 9, Table 3). The uneven spatial distribution of scars is an interesting outcome because it indicates that spatial management actions could be targeted to intervene with factors that are leading to concentration of scarring in certain areas. An initial hypothesis of stakeholders was that scarring would be most dense directly adjacent to the keys, as they represent areas that are often targeted by anglers. The area within buffer zones around the keys sometimes exceeded the background light scarring density (overall average) of the study area of 125 ft^2/ac, especially within closer distances. Scarring densities of light scars for the total buffered area (0-1000 ft) around each key ranged from 37 to 666 ft^2/ac, with 6 out of 24 keys having scarring densities above background and key 1 having a scarring density more than 4x background (500 ft^2/ac). When looking at the 0-600 ft buffered area, scarring densities increase somewhat (range 28 – 1073 ft^2/ac), with 9 of 24 keys having scarring densities higher than background and key 1 having a scarring density of more than 8x background (1000 ft^2/ac, Appendix C). Finally, within the 0-300 ft buffered area, scarring densities were highest (range 13 – 1,659 ft^2/ac). Within the 0-300 ft buffer, 13 of 24 keys had scarring densities that exceeded background level, and key 2 had scarring that was more than 4x background, while key 1 scarring density exceeded 8x background. Therefore, the stakeholder hypothesis is somewhat supported, especially for the 600-ft and 300-ft buffers, but this pattern is not uniform, with scarring clearly concentrated around certain keys more than others.

Although any level of propeller scaring is undesirable and will result in negative impacts to ecosystem services, one possible approach to address the aberrant scaring around Keys 1 and 2 would be to establish a management zone around these keys at a distance at which scaring density becomes similar to other keys. Figure 10 illustrates light scar densities within 100 ft concentric buffer zones out to 1000’ around each key. Keys 1 and 2 show significantly higher scaring densities out to approximately 800 and 600 ft, respectively. Assuming management practices implemented do not result in redirecting boating pressure to other keys, management actions that reduce scaring within these two areas could bring impacts around these keys to levels similar to other buffer areas within the St. Martins Keys.

We attempted to evaluate if propeller scaring within the St. Martins Keys has increased relative to previous surveys; however, methods used were not compatible and therefore no assessment of change in propeller scar density over time could be made. The most recent propeller scar mapping effort by Wood Infrastructure and Environment, Inc. (Wood) in 2018 used lower resolution aerial imagery and a different methodology to assign scar impacts. In this study, individual propeller scars were identified and traced resulting in a spatial quantification of scars that could be evaluated in linear feet or square feet per unit area. The methodology used by Wood did not identify individual scars but instead used a three-tier scar severity classification (minor, moderate, severe) by demarcating polygons on an aerial image. No specific number of propeller scars, scars per area or total linear feet of scaring were associated with the three-scar severity categories and therefore they could not be compared to our survey. Attempts to quantify scar densities within each of the three scar severity categories using the Wood 2018 imagery resulted in a discrepancy between scar severity categories and actual scar density (see Table A2). Therefore, in addition to significant difference in the resolution of imagery being used to identify scars, which would skew comparison of results by itself, the Wood 2018 analysis was not compatible without a lengthy reevaluation of their aerial imagery using our individual propeller scar tracing approach. Therefore, we are not able to offer any quantitative information regarding the trends in scarring densities in the study area.

Table 1. *Scaring categories observed in aerial imagery and used to define scar type during assessment.*

Scar type	Description
Light	Scars in seagrass that are light in color relative to adjacent spectral signature. The bright or light spectral signature of these scars relative to adjacent dark seagrass suggest boat contact has exposed underlying mineral sediment. (Figure A5)
Dark	Scars in seagrass that are dark in color relative to the adjacent spectral signature. These scars were common in imagery and suggest interaction of boat propeller with the seagrass, but not so deep as to expose the underlying mineral substrate. (Figure A6)
Hardbottom	Scars in hardbottom communities that are lighter in color than adjacent spectral signature. These scars represent areas were macro algae and potentially other attached benthic organisms such as sponges have been dislodged by the propwash and potentially direct contact with prop and lower unit resulting in a lighter signature of the mineral bottom being expressed relative to adjacent areas. (Figure A7)
Airboat	Wide (6-8’) and uniform deviation in spectral signatures typically in seagrass areas. (Figure A8)

Table 2. *Overall linear feet, aerial coverage, and density of propeller scars within the total mapping boundary. Estimates for restoration costs and ecosystem service impacts are provided for light scars only.*

Scar type	Total length (ft)	Total area (ac)	Scarring density, length (ft/ac)	Scarring density, area (ft^2/ac)	Estimated restoration cost (USD)	Estimated ecosystem service value impacted (USD/yr)
Light	256,753	7.172	107	125	$5,135,060 to $15,620,615	$83,856
Dark	89,623	1.781	37	31	-	-
Hardbottom	19,802	1.790	8	31	-	-
Airboat	75	0.014	0	0	-	-

Table 3. *Propeller scar summary from the 0-600-ft buffer around each of the St. Martins Keys (Key IDs reference IDs presented in Figure 3).*

Key ID	Total scar length (ft)	Total scar area (ft^2)	Scar density, length (ft/ac)	Scar density, area (ft^2/ac)
1	44,169	53,745	1,073	1,306
2	29,411	35,787	456	554
3	8,157	9,926	135	164
4	12,691	15,442	167	203
5	7,963	9,689	215	261
6	5,345	6,504	75	91
7	1,225	1,491	43	52
8	1,471	1,790	71	86
9	2,481	3,019	42	51
10	1,597	1,943	64	77
11	1,260	1,533	55	66
12	3,592	4,371	103	126
13	9,829	11,960	125	152
14	5,734	6,977	245	298
15	2,772	3,372	62	75
16	4,454	5,420	104	126
17	1,758	2,140	39	47
18	936	1,138	28	34
19	4,835	5,883	137	167
20	4,635	5,640	108	132
21	2,821	3,432	99	120
Crawl Key	12,462	15,164	219	266
Green Key	1,940	2,360	81	98
Sand Key	5,545	6,747	142	173
Total	177,082	215,474	3,886	4,728

Figure 3. *The St. Martins Keys included in the present mapping effort, 24 in total.*

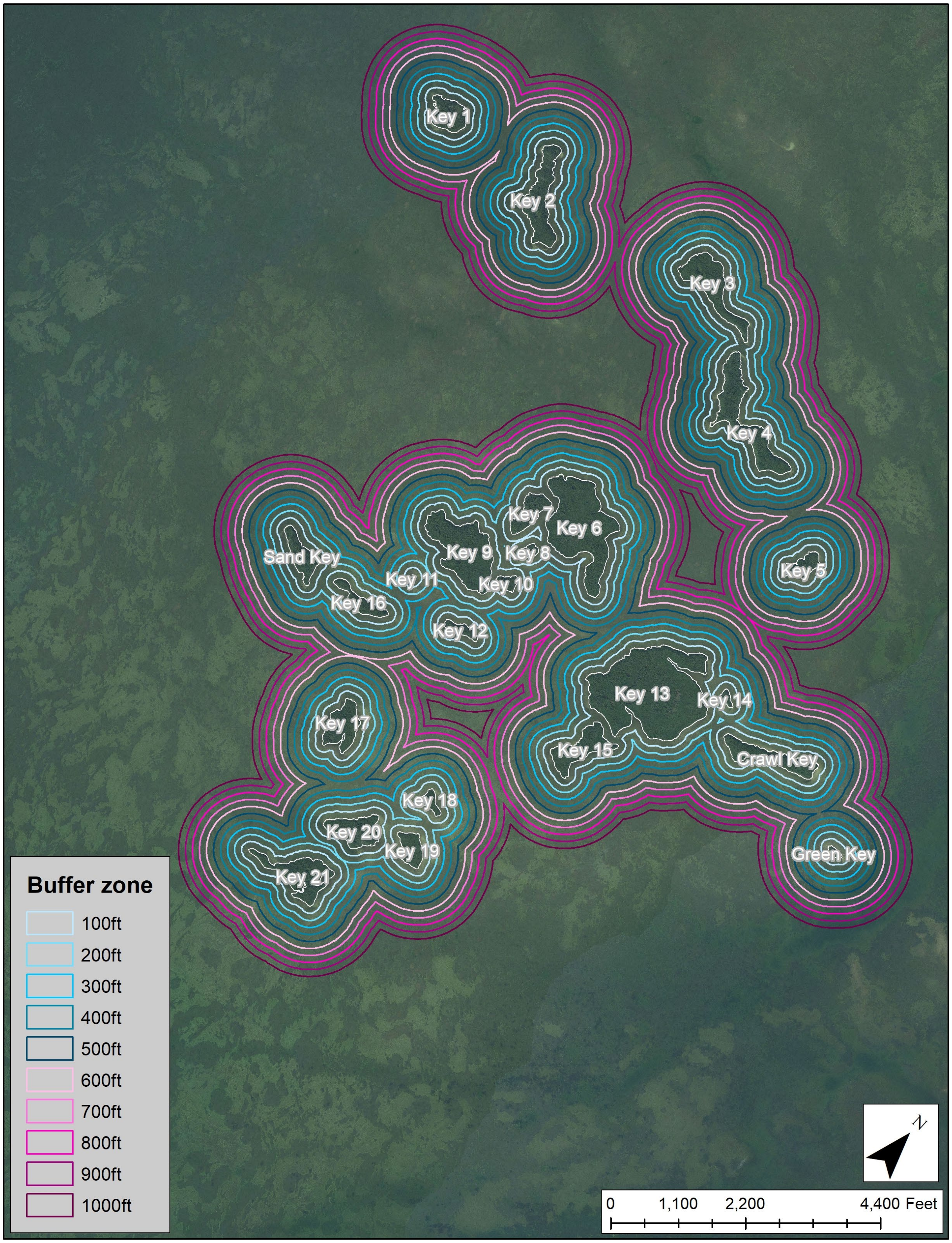

Figure 4. *Buffer zones around each key that were analyzed for propeller scarring characteristics.*

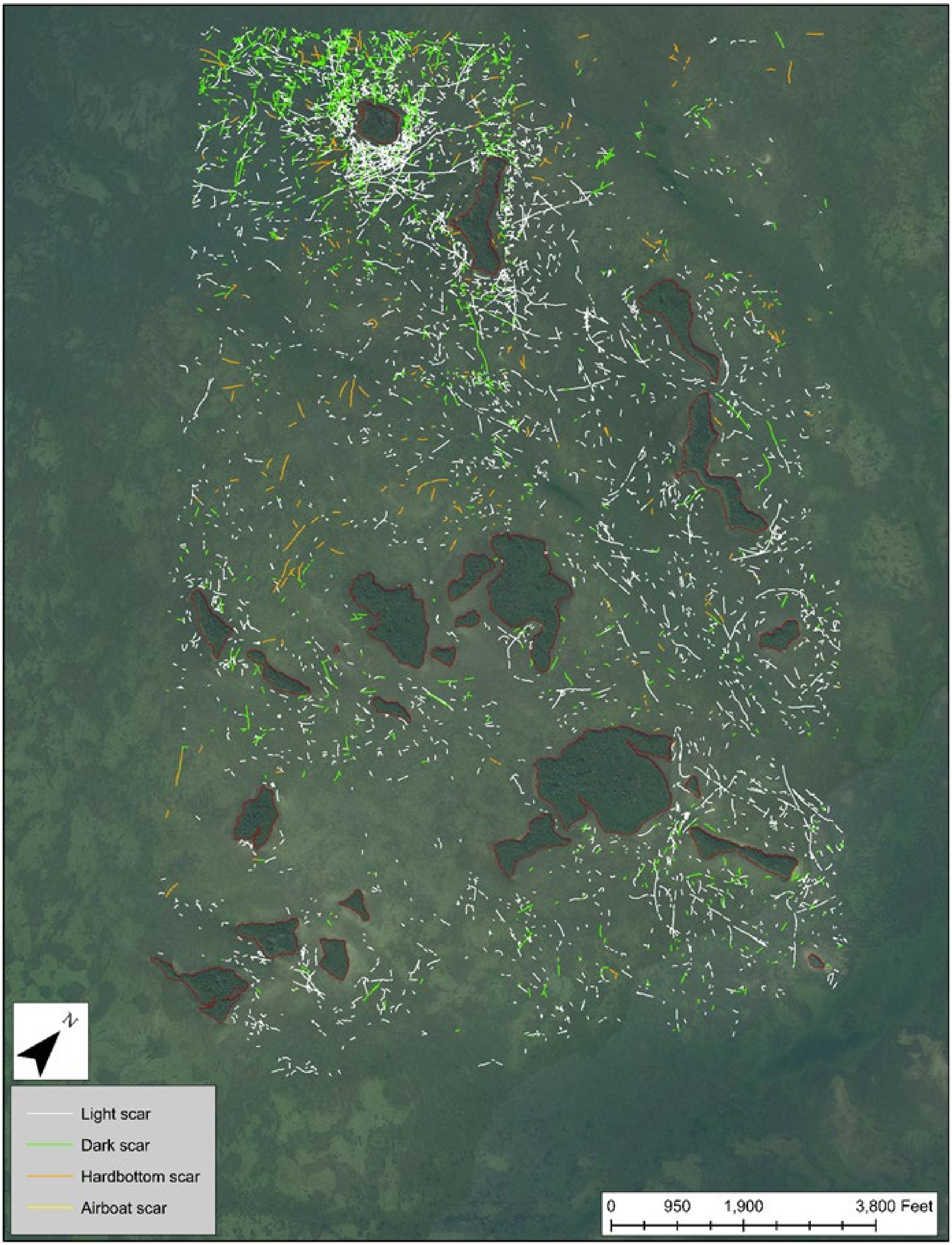

Figure 5. *Overall distribution of propeller scars of four types within the St. Martins Keys study area.*

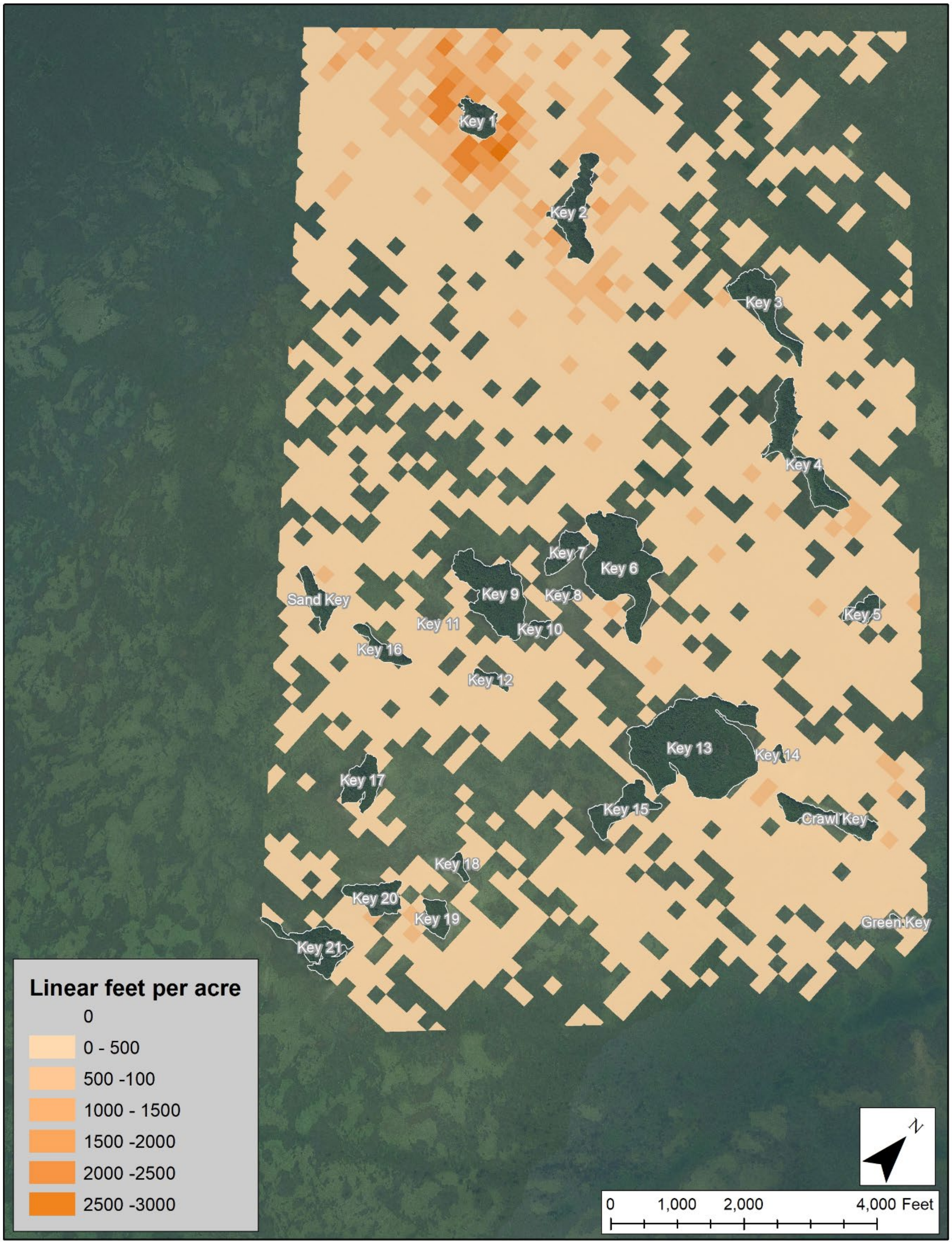

Figure 6. *Density of all scars combined (liner feet per acre) based on 1-acre fishnet mesh throughout the study area.*

Figure 7. *Distribution of propeller scars of four types within the St. Martins Keys study area, shown using a 300-ft buffer distance from the perimeter of each of the 24 keys. The red line represents the total mapped area.*

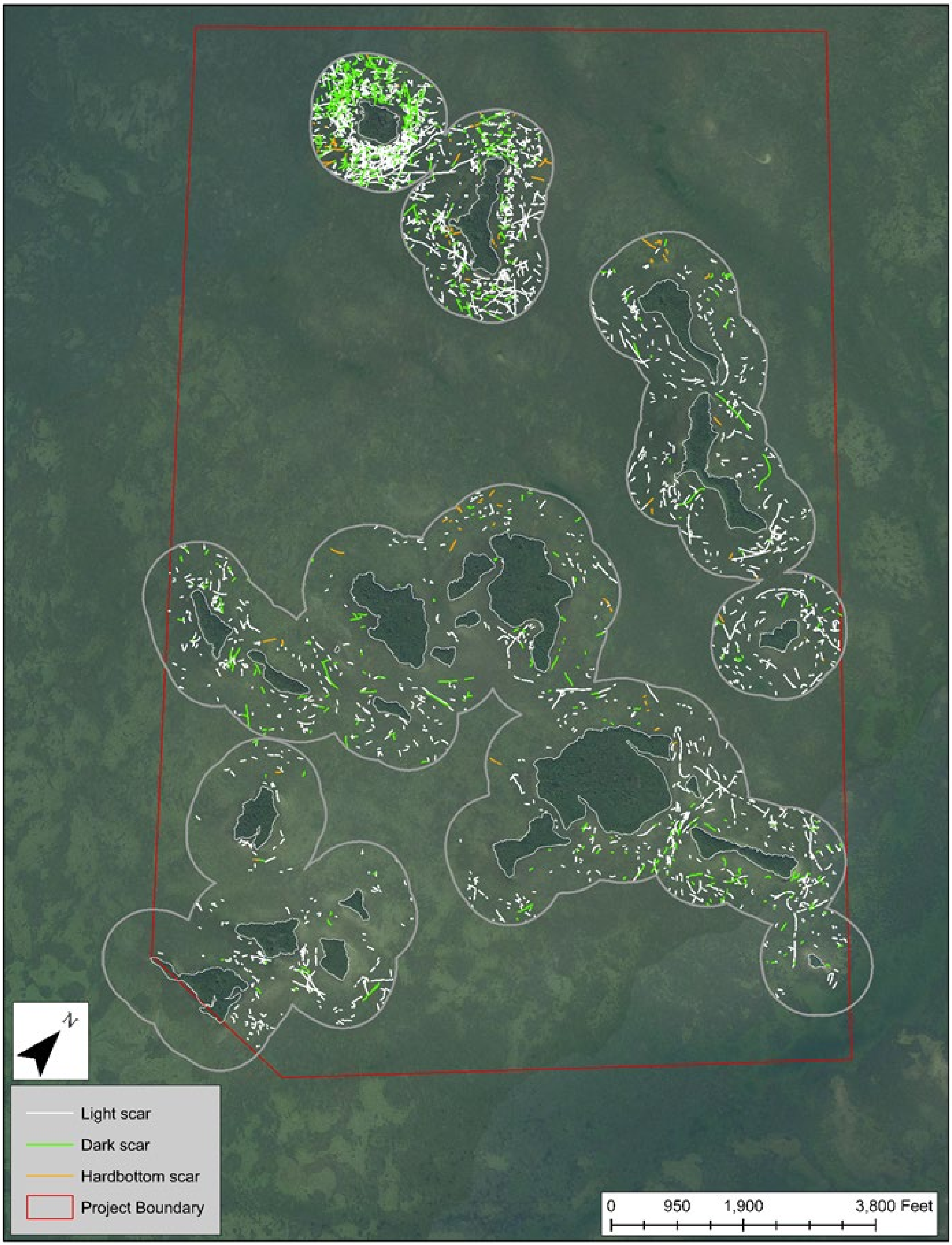

Figure 8. *Distribution of propeller scars of four types within the St. Martins Keys study area, shown using a 600-ft buffer distance from the perimeter of each of the 24 keys. The red line represents the total mapped area.*

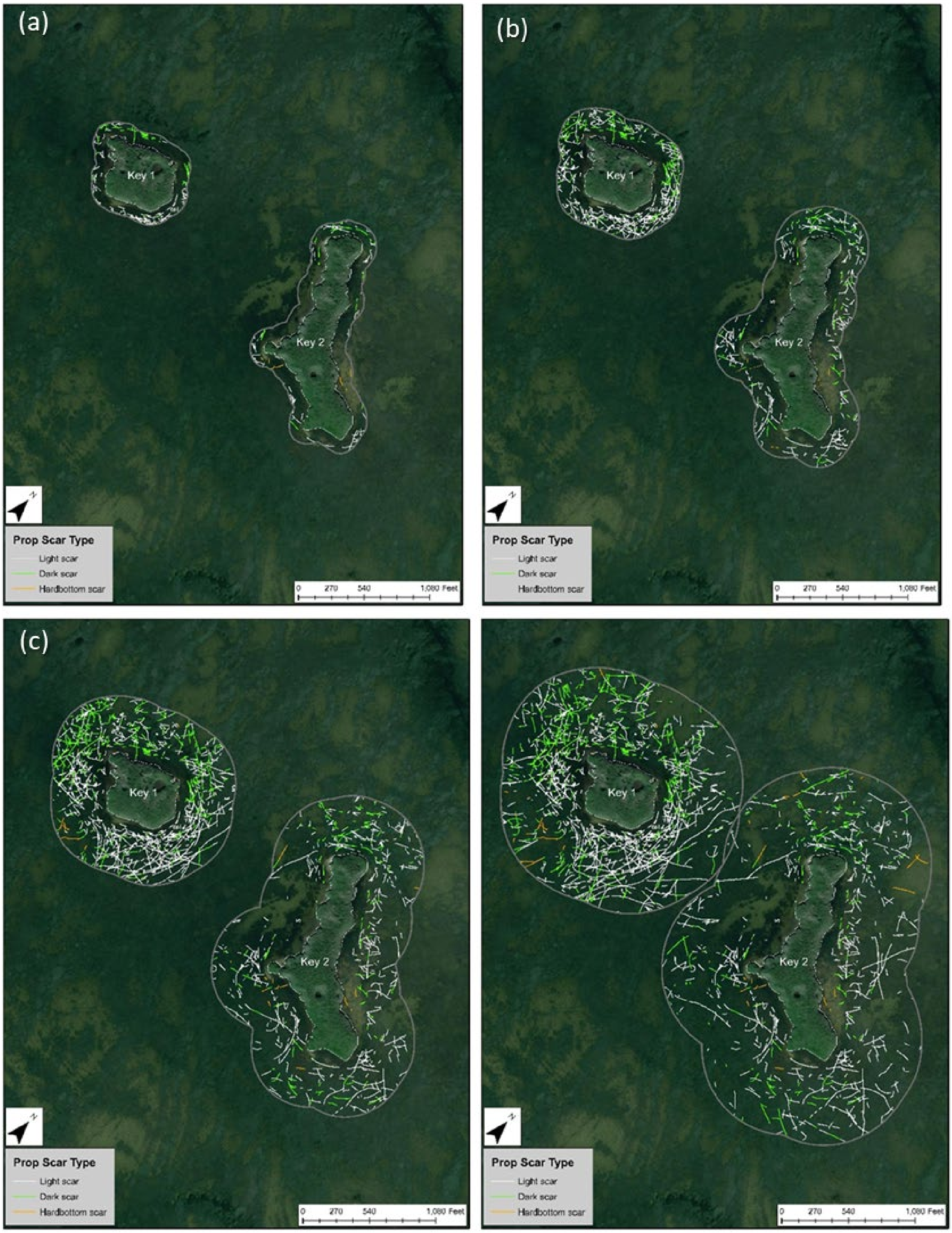

Figure 9. *Distribution of propeller scars within 100 (a), 200 (b), 400 (c) and 600 (d) foot buffers around Keys 1 and 2, where scarring density is the highest.*

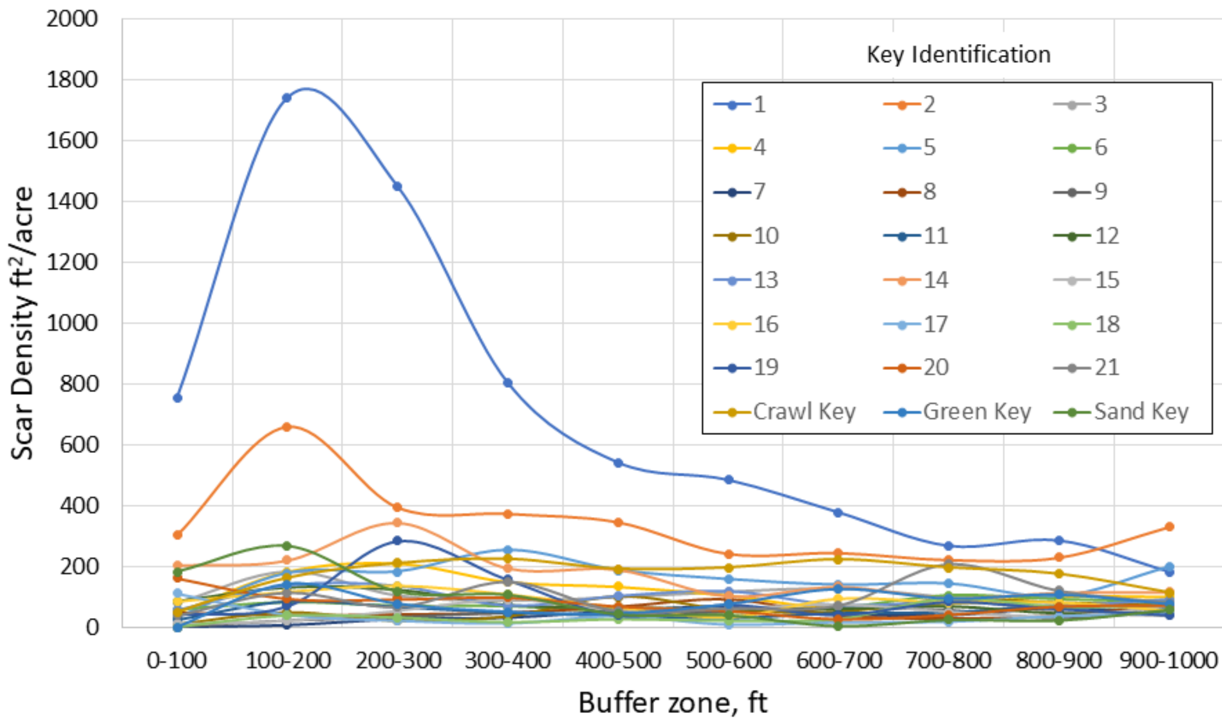

Figure 10. *Light scar propeller density within 100' concentric buffers surrounding each of the 24 St. Martins Keys.*

Part 2: Analysis of Policy Options to Protect Habitat and Enhance Fisheries

Boating-Restricted Areas and Seagrass Protection in Florida

Creating spatial restrictions on boating activity to protect seagrass requires approval from the state agencies responsible for activities on navigable waters, and these agencies are themselves constrained by the Florida Legislature. Local governments can also create boating restricted areas, but this authority is limited in scope, and requires state approval.

Three Florida agencies share jurisdiction over the submerged lands and navigable waters in the State. The Governor and Cabinet, sitting as the Trustees of the Internal Improvement Trust Fund (TIITF), hold submerged lands that have not been alienated in trust for the people of Florida. The Florida Department of Environmental Protection (FDEP) serves as the administrator to the TIITF for submerged lands matters. FDEP also has statutory authority over navigable waters for the purposes of administering water quality programs. The Florida Fish and Wildlife Conservation Commission (FWC) administers the State's boating and fishing laws. FDEP and FWC's authority is derived from, and constrained by, statutes enacted by the Florida Legislature.

The Role of FWC

Section 327.46, Florida Statutes authorizes FWC to establish boating restricted areas "for any purpose necessary to protect the safety of the public if such restrictions are necessary based on accidents, visibility, hazardous currents or water levels, vessel traffic congestion, or other navigational hazards or to protect seagrasses on <u>privately owned</u> submerged lands." (emphasis supplied). Thus, absent exceptions, the only reason FWC can create a boating restricted area comes from its relationship to public safety. This suggests that FWC does not have statutory authority to create boating restricted areas solely to protect habitat – with two exceptions. The first, and most recent, is for seagrass, but it is limited to seagrass on "privately owned submerged lands." Although explicitly protective of seagrass, this carve-out has limited applicability. The vast majority of submerged lands in Florida remain in public ownership. The rationale for this recent change to Florida law may be to encourage the use of mitigation banking for seagrass on those privately owned submerged lands that do exist. The second exception is for the protection of manatees and their habitat. Under the Florida Manatee Sanctuary Act, Section 379.2431(2), Florida Statutes, FWC can adopt rules to "protect manatee habitat, such as seagrass beds, within such waters, from destruction by boats or other human activity."

The Role of Local Governments

Florida's boating statute does grant the authority to establish boating restricted areas to local governments – counties and municipalities, but these are limited in type to those that are listed in the statutes (Ankersen et al, 2019). This statutory list is largely related to public safety concerns. None of the listed types address protective measures for environmental purposes, including the protection of seagrass. In addition, local governments must secure permission from FWC before enacting a local boating restricted area ordinance.

The Role of the Trustees and Florida Department of Environmental Protection

Under federal law lands beneath the navigable waters were transferred to original thirteen colonies at the time of union, and to the remaining states at the time of statehood. In Florida, a special agency was set up to administer state lands known as the Board of Trustees of the Internal Improvement Trust Fund. The Governor and Cabinet act as these Trustees. Under case law, the federal transfer requires that the state hold the submerged lands in trust for the people of the state for purposes of fishing, swimming and navigation, under a limiting legal doctrine known as the public trust doctrine. While these limitations were often disregarded as Florida developed, outright transfer to the private sector has been rare more recently.

The Florida Department of Environmental Protection administers the State's submerged lands on behalf of the Governor and Cabinet. Chapter 253, Florida Statutes serves as the basis for state administration and management of all state lands, including submerged lands. Section 253.04(1) provides that the Trustees may "police; protect; conserve; improve; and prevent trespass, damage, or depredation upon such lands and the products thereof,…" Authority to administer state lands is then delegated to FDEP by the Trustees pursuant to Title 18 of the Florida Administrative Code. Thus, it seems clear that the Trustees and FDEP have authority as the landowner and trustee to regulate and manage activities on submerged lands and the overlying waters. This authority relates not to public safety, but in order to protect those lands and "the products thereof" based to their charge as trustee. The term product is administratively defined to include "indigenous, planted or exotic trees and other vegetation, or portions thereof…." Seagrass would likely fall under the broad category of "other vegetation" and would therefore be a product within the meaning of the statute, and under the administrative authority of FDEP.

Additionally, seagrass has been called out for special consideration by the legislature. Section 253.04(3)(A) provides that the Board of TIITF and, by delegation, DEP, have a duty to ensure the “preservation and regeneration of seagrass, which is essential to oceans, gulfs, estuaries, and shorelines of the state.”

Current Practice and Case Studies

There are several discrete, spatially described protected seagrass beds on sovereign submerged lands in Florida, most of which were established to curtail boat traffic and reduce or eliminate propeller scarring and are typically used as mitigation for impacts to seagrasses and aquatic resources elsewhere. These are typically designated as NICMZs – No Internal Combustion Motor Zones (Hotaling, et al, 2011). These zones are established through a State (Trustees) transfer of a property interest in sovereign submerged lands to a third party using one of several forms of submerged lands use authorizations allowed under Chapter 253, Florida Statutes and its implementing regulation, Florida Administrative Code Rule 18-21. The forms of submerged lands use authorization used by the Trustees to convey an interest in sovereign submerged lands include 1) Specified Exceptions (no authorization required), 2) Consent by Rule, 3) Letter of Consent, 3) Lease, 4) Easements and 5) Use Agreement (limited to geophysical testing). The nomenclature for these has changed from time to time.

Examples of NICMZ’s established by the Trustees/DEP for the protection of seagrass and their associated form of use authorization are provided below (Table 4).

Letter of Consent. An 89-acre NICMZ is established in the Lemon Bay Aquatic Preserve in Southwest Florida. This NICMZ was granted as mitigation for a noticed general permit given to the Southwest Florida Inland Navigation District to conduct channel dredging. To manage the area and limit boat traffic to “pole and troll” vessels, the Trustees/DEP granted WCIND a “Letter of Consent,” for the use of the submerged lands.

Conservation Easement. A 181-acre seagrass mitigation bank was established through the grant of a conservation easement over submerged lands to the Southwest Florida Water Management District. The submerged lands were owned by the County, which are in a perpetual conservation easement.

Lease. The Pinellas County-managed Weedon Island Preserve created a NICMZ to protect “seagrasses and aquatic resources” through a lease from the Trustees for an areas designated in the Weedon Island Preserve Management Plan. Similarly, seagrasses surrounding several islands associated with Shell Key in Pinellas County have been protected through NICMZs that are created through a lease agreement from the Trustees.

A lease also serves as the basis to grant Lee County authority to create a “pole and troll” zone on the Wulfert Flats Management Area within the Ding Darling National Wildlife Refuge. The NICMZ was created to serve as mitigation for seagrass impacts due the dredging of Blind Pass between Sanibel and Captiva Islands.

Management Authority. In Honeymoon Island State Park, Pinellas County, FDEP received “management authority” from the Trustees over some of the submerged lands within the park to establish an NICMZ 400 feet out from the shoreline.

Spatial Fisheries Management

This section discusses the potential for the implementation of differential, spatially explicit fishing management techniques within Florida marine waters. The Florida Fish and Wildlife Conservation Commission (FWC) has a broad mandate under the Florida Constitution to regulate the behaviors of people fishing within its waters. Article IV, Section 9 of the Florida Constitution establishes the FWC as a body of seven commissioners appointed by the governor. The Florida Constitution grants the FWC "the regulatory and executive powers of the state with respect to … marine life" (FC Art. IV, §9). Under this mandate, and with ample precedent, it is possible for to pursue spatially explicit recreational fishery management strategies within the St. Martins Marsh Aquatic Preserve (SMMAP). Catch and release areas and size-based management areas are examples of management strategies that could potentially be introduced into the SMMAP in order to enhance the fishery and tailor it toward a specific clientele. These approaches are presently employed in other bodies of water within Florida, both salt and fresh.

Special management areas have most often been enacted by FWC in order to protect fish populations that are experiencing pressures and need extra enforcement. In the recent past, they have been enacted in marine environments on an individual species basis as a response to external, unexpected threats such as red tide and cold snaps. These marine catch and release (CR) areas have targeted important recreational species, such as spotted seatrout, redfish and snook. When these events put added stress on a population in an area it has been deemed necessary to grant them extra protection of a CR zone. These emergency CR zones have been created since 2010 by executive order of the director of the FWC. They have been crafted for both specific species, as well as in particular areas. The species that have been protected in the recent past are redfish, snook, and spotted sea trout. They were used in response to an unexpected cold snap in 2010 that resulted in damage to snook populations (EO 10-45). Currently there are two active executive orders, EO 21-07 and EO 21-16, that establish CR zones encompassing an area from Collier County to Manatee County.

Examples of CR areas in freshwater can be found throughout the Florida fishing regulations established by the FWC. Examples of catch and release of specific species include the Shoal bass on the Chipola river and Black bass in Wildcat Lake. Other species require special permits if they are to be kept, such as Grass carp and Alligator gar, and otherwise must be released immediately. As noted elsewhere in this report, pole and troll areas have been established in salt water to protect seagrass, and in fresh water, as in Picnic lake. Additionally, differential size requirements have been established, such as in Lakes B and 5, where Black bass over 16 inches must be released immediately (*See* Florida Freshwater Fishing Regulations).

In order to establish a spatially explicit management approach, FWC must go through a rulemaking process. The Director has the authority to "initiate rule development," starting the rulemaking process (DoA, ¶16). Once initiated the rule must be approved by the Commission, and then advertised and published in the Florida Administrative Weekly before it can be finally published.

Table 4. *List of boating restricted areas established to protect seagrass.*

Name of Zone	Location	Year Est.	Size (Acres)	Instrument Type	Citation and Notes
Lemon Bay Aquatic Preserve	Englewood	1986	89	General Permit	Rule 62-330.411 F.A.C.
North Shore Park	St. Petersburg	2017	161	Conservation Easement/City Ordinance	Ord. No. 788-G, § 1, 9-21-2006 Restoration Plan
Honeymoon Island State Park	Pinellas County	1994	Map	Management Agreement	MA 68-086 Management Plan
Weedon Island Preserve	Pinellas County	1993	Map	Lease Agreement/City Ordinance	Ord. No. 00-93
Shell Key Aquatic Preserve	Pinellas County	1993	Map	Lease Agreement/City Ordinance	Ord. No. 00-93
Wulfert Flats Management Area	Lee County	2008	474	Joint Coastal Permit	see Blind Pass Mgmt Study 2018 From permit final order: "As mitigation, dune areas on Captiva Island will be restored, mangroves will be planted in Clam Bayou, and a No Motor Zone will be created near Wulfert Keys to promote the recovery of seagrasses damaged by prop-scars."

Part 3: Potential Outcomes of Special Management Actions

Background

Recreational fisheries are almost always actively managed by state or federal agencies for both ecological and socioeconomic concerns. Fisheries managers seek to sustain aquatic ecosystems and fish populations. Successful fisheries management includes strategies to ensure that harvest rates aren't too high and that fish have suitable habitat, especially for recruitment. At the same time, fisheries managers also want to ensure that stakeholders—recreational fishers—are reasonably happy, and that fishing continues to produce market activity (revenue, jobs) for local communities. One of the most important metrics for both the ecological and socioeconomic goals is fishing effort.

Recreational fishing effort plays a critical role in fisheries ecological and socioeconomic sustainability. Fishing effort usually directly negatively affects fish populations. This is because if nothing else changes, more fishing effort leads to greater harvest and fewer fish. However, this relationship isn't linear owing to fish recruitment dynamics, which allows for sustainable fishing (Camp et al. 2020; 2021). On the socioeconomic side, greater fishing effort indicates anglers are getting greater utility from fishing, and utility is related to satisfaction or happiness with fishing. Greater fishing effort also almost always means greater fishing-related revenue—the money spent on fishing trips and related purchases. This increased market activity can support local economies and jobs. Practically, this means many local areas may see increases in fishing effort as a good thing, since it should lead to enhanced market activity, at least in the short term. Again, there is a balance—if the fishing effort increases by so much that it decreases fish populations and catch rates substantially, this may eventually lead to greater or longer-lasting decreases in fishing effort. What all of this means is that it's very important to understand how potential management actions are likely to affect fishing effort.

The challenge is that assessing how recreational fishing effort will be affected by a management action is not easy. Effects on fishing effort can even be counterintuitive, often because of complex dynamics and feedbacks between human behaviors and their effects (Camp et al. 2016). This summary first describes some of the processes by which management actions can change fishing effort. Then, we describe some examples from the literature that show how some specific, common management actions could have a range of different effects of fishing effort. Finally, we describe how the potential management actions considered for the St. Martins Keys area might reasonably be thought to affect fishing effort in Citrus County, and what would be needed to be more confident in what these effects would be.

Processes for how management can affect recreational fishing effort

Management actions can affect recreational fishing effort directly, indirectly, and via feedbacks. To understand how these processes work, it is necessary to explain a bit about the current understanding of recreational fisheries and angler behavior.

Most recreational fisheries in North America, and all those in Florida, are "open access". This means that the total amount of fishing trips, as well as license holders, is not limited. There are no rules about how many fishing licenses can be sold, or how many fishing trips can be made. There are, however, rules about how fishers can fish (type of fishing gear used), how many fish each person can harvest, and goals for the total amount of biomass harvested. In some locations, there are also special regulations for how fishers get to this fish—for example, no-motor zones or poll and troll zones. But in general, open-access means is that fishing effort can fluctuate freely depending on how much fishers want to fish given the other rules. If there is more demand for fishing, there will be more trips, as vice versa.

The modern economic theory of utility describes that demand for leisure activities like recreational fishing will change according to the "utility" participants derive. Utility here is essentially satisfaction or enjoyment from fishing. Things that increase fisher satisfaction should eventually lead to increased fishing effort. Many things affect the satisfaction (utility) that recreational fishers attain from fishing. These are described in terms of catch-related and non-catch related metrics. Catch-related metrics include things like catch rate, catch size, number of fish harvested, etc. Non-catch related metrics can include things like fishing site characteristics—such as the habitat in the area fished, or the quality of the ramp facilities. Additional information about the current science of utility and satisfaction can be found in recent articles by Hunt et al. (2019) and Birdsong et al. (2021). The point is that changes to catch and non-catch related metrics (like facilities or catch rates) should affect demand for fishing, which in turn affects total fishing effort (I.e., number of trips).

Both catch and non-catch-related metrics can be affected by fisheries management decisions. Fisheries management decisions can mostly be categorized into two groups. Restrictive actions like harvest limits and closed seasons tend to restrict angler behaviors which affects especially catch metrics and ultimately utility and demand for fishing. Augmentative actions like habitat restoration, stock enhancement, or facilities improvement can affect catch or non-catch metrics, and again, affect utility and demand for fishing. What this means is that while some recreational fisheries management actions can more directly affect fishing effort, many do so either indirectly or via feedbacks between fish population dynamics and fishers. These different ways are described below.

Direct effects

In open-access fisheries like those in Florida, it is less common that fisheries management decisions directly alter fishing effort, but it can or could happen. The easiest way for this to occur would be rules that prohibit fishing during a certain time or for certain areas. These types of rules are quite common in other states, which often have seasonal closures on fishing on certain waters (e.g., for salmonid trout, walleye, or black bass) with annual "opening days" when anglers are again allowed to fish for the species. Some potential examples of (more) direct effects of management of fishing effort in Florida might include:

- Changes in fishing (not harvest) season. For example, a seasonal closure for bottom fishing to decrease discard mortality (Chagaris et al. 2019). This would limit the total number of days available for fishing and would have some direct (though maybe not linear) effect on total fishing.
- If an additional boat ramp lane or parking is added, this would almost certainly increase the utility experience either per angler, or the number of anglers that benefit. Either way, more fishing trips would be expected.

- Changes in the type or use of vessels allowed in certain waters, such as no-motor zones, or non-motorized vessels (e.g., kayaks), or no-airboats. This would restrict the number of people allowed to fish an area and could influence overall effort.

Indirect effects

Indirect effects of management actions on fishing effort are probably much more common. These include all the cases where a management action would limit one thing (like harvest allowed) which would then affect how much anglers want to fish, and thus the demand for trips and effort. This could also happen with non-restrictive, augmentative actions. Finally, there are often indirect effects that follow direct effects. That is, just because there is a direct effect, that does not mean that direct effect tells the entire story of how effort would change. Here are some examples of indirect effects:

- Changing the minimum size limit of a fish, such as an increase in the minimum size limit of tripletail from 15" to 18". This may change whether potential tripletail anglers think they'll be able to harvest a fish, and may alter whether they choose to fish for tripletail (or at all!) and thus effort.
- Habitat restoration/enhancement could make it more enjoyable to fish and lead to more effort. For example, restored mangroves may create a more aesthetically pleasing experience that attracts more anglers. Or adding artificial reefs or fish attractors could lead to anglers believing they'll have better fishing.
- A change in the type or use of vessel could also have indirect effects in addition to direct effects. For example, airboats being prohibited from a National Wildlife Refuge estuary might initially be thought to decrease effort (since it would limit allowable vessels). But this action might have the indirect effect of creating an experience more enjoyable to anglers who dislike the noise from airboats, and could actually lead to net no-change or even increase in effort.

Feedbacks

The tricky thing about fishing effort is that it's not just affected by things like management actions, it also affects and is affected by fish populations. Thus, when a management action changes fishing effort, that effort influences the fish population, which could in turn further effect effort, and so on. These complex dynamics are called "feedbacks". The feedbacks create linked systems between fishers and fish, much the same as between predators and prey. Some examples of common fisher-fish feedbacks in recreational fishing systems might include:

- A change in the allowable bag limit. For example, if the red drum bag limit changes from 2 to 1 per day per person, this would immediately alter the satisfaction or utility that some fishers receive, and would likely cause some people to fish less for redfish. But perhaps the decrease in harvest (by lowering the bag and/or less fishing) causes the number or size of redfish caught to increase. This in turn might cause more people to fish for redfish, even though they couldn't keep them.
- A change in the type or use of a vessel could also trigger feedbacks. Following the example above of airboats prohibited from a NWR: if this exclusion results in greater abundances or catch rates of fish, non-airboat anglers may be attracted to the area even

if they do not dislike hearing airboats. But then the feedbacks continue. If so many anglers are attracted (for whatever reason) to the NWR, the fish populations and catch rates could decline back again and lead to a leveling off of effort.

The final example describes a more general expectation of feedbacks, which is that they often tend to moderate or “dull” the eventual effects. If a management action leads to an initially large increase in effort, it’s likely that effect will shrink over time as the increased effort translates to more harvest, smaller fish populations, and lower catch rates and/or size. Conversely, if the initial effect of a management action decreases fishing effort (such as a spatial closure), it’s possible that the resulting fish population increase will cause catch size and rate to increase enough for effort to come back up some. It is important to remember, though, that these moderating feedbacks (1) often take time—especially when they depend on a fish population rebuilding (which can take decades), and (2) they aren’t guaranteed.

It is worth noting that there are specific, usually ecological relationships where once a change occurs, it may not readily change back. A system can “flip” into a different pattern and may resist changing back, referred to by ecologists as “alternative stable states”. These are known to occur especially with habitat forming organisms such as seagrass, oysters, and mangroves that may be particularly important to fish. These organisms create structure that is important to fish, but perhaps even more critically, that holds sediment, buffers wave energy, and prevents erosion, and thus promoting clearer, calmer conditions in which they proliferate. If the habitats become too sparse, they will eventually fail to do this, hastening long time.

The main point to understand with effort responses is that it is not easy to predict the eventual (equilibrium) total effect. There can be a combination of direct, indirect, and feedback effects for any management action. The strength of these effects may differ, and they may take some time to show up. This brings up an important sub-point, which is effects of management decisions that involve feedbacks of long-lived species may take a long time to be apparent. This is because most (not all) feedbacks involve fish populations, and population dynamics of long-lived species can take a while to change. For example, the Florida redfish fishery is almost wholly targeted on 2-4 year old fish that successfully recruited from young-of-year. If the population becomes overfished (where recruitment declines because of limited by egg production of adults), it might take many years to rebuild that spawning stock, to the point at which recruitment and then the abundance of catchable 2-4 year old fish is noticeable to anglers. A second important point is that some management actions (or inaction) can have even longer effects if they trigger changes in habitat that transition to alternative stable states. Management action or inaction that allows loss of habitat forming organisms like seagrass, salt marsh grass, oysters, or mangroves may be semi-permanent. This is because these habitats can apparently transition to alternative stable states where recolonization in nearly impossible, and are also thought to be key habitats important for juvenile fish survival.

Fisheries case studies

We examined the fisheries scientific literature to look for examples of how management actions resulted in altered effort dynamics. A few examples are listed below, with the authors, year, and summarized subject of the study. The full citations are available in the references.

- *Cornelius and Margenau (1999): Effects of length limits on a musky fishery.* The authors found evidence that effort increased following the imposition of regulations and concomitantly to increasing size of fish and catch rates, both of fisheries independent gear and the recreational fishery. This could be taken as evidence that angler decisions to target certain fish are positively related to size and abundance of that fish. So, this study showed that harvest restrictions actually increased fishing effort.
- *Newman and Hoff (2000): Effects of minimum length limits on a smallmouth bass fishery.* The authors found that effort increased following imposition of length limits in a single lake smallmouth bass fishery in Wisconsin. Overall catch per unit effort (CPUE) and CPUE of quality fish increased, leading authors to infer that anglers in this fishery cared more about catch rates of quality fish (as measured by the increase in effort) than they did the harvest potential of smallmouths. Ultimately, this study showed that harvest restrictions resulted in an increase in fishing effort.
- *Muoneke 1994 Dynamics of a heavily exploited white bass fishery in Texas*. These authors described as system where harvest restrictions were imposed and found that effort decreased immediately after (but rebounded the next year), while catch rates remained similar. These results are based on only a few years of data, but do serve as evidence that imposition of harvest restrictions can have an effect on effort, even in the absence of noted changes in the catch rates. So the take-home message from this study was that harvest restrictions could cause a decrease in fishing effort.
- *Boxrucker 2002 Rescinding a minimum length limit for white crappie in a lake in Texas.* This study looked at a white crappie fishery that was believed to be strongly affected by fishing, and generally having a lower abundance of large fish. A minimum length limit (a harvest restriction) was established, and resulted in increase in larger fish. Catch rates increased, but harvest rates (by number and weight) declined, likely because of fewer legally harvestable fish being caught under the new length limit. Effort eventually decreased substantially, suggesting that harvest was more important to anglers than fish size or catch rates for this fishery. Thus, this is another example of stricter harvest regulations having a negative effect on effort.

Examples from Florida and other Estuarine Systems

But what about how changes in spatial regulations, like vessel type or use, effect effort and the rest of the fishery system? And since the examples above seem to indicate that the effects of management actions depend on specific species and or systems, shouldn't we specifically look at systems in Florida where this occurred? The challenge is that there is limited literature on this specific situation. Given the open-access nature of fishery resources, use of spatially constrained effort restrictions (e.g., no motor zones, closed areas, gear limitations) are not common in estuarine systems. Use of marine protected areas (MPAs) has occurred globally, but mainly in offshore/reef fish applications in Florida, remaining relatively rare for inshore/estuarine zones. What we have done is to summarize some of the known cases where there were spatial closures/changes implemented, and describe what effects these appeared to have on some of the fishery metrics, including fish abundance, catch rates, and potentially fishing effort.

- Stevens and Sulak (2001) – Merritt Island National Wildlife Refuge. This tagging study evaluated fish immigration from a closed area around Kennedy Space Center. They tagged 3,358 total fish including Red Drum, Spotted Seatrout, Black Drum and Common Snook. They found that tagged fish showed limited movement out of the closed area and were only occasionally captured by anglers in adjoining waters. The study concluded that the closed area effectively protected fish populations within the closed area and provided recruitment of fish into the open-access zone adjacent to the refuge area. The work emphasized that, for estuarine fishes with relatively small home ranges, protected areas can effectively limit fishing mortality and provide some recruitment of fish into adjacent open-access areas.
- Bohnsack (2011) – This study evaluated game fish world record catches around closed areas around Cape Canaveral and Everglades National Park. Catches of world-record size sport fish including Spotted Seatrout, Red Drum and Black Drum increased particularly around the Cape Canaveral closed area, and the study found that both closed areas increased the size and catch per effort of sport fish in areas adjacent to the closed areas.
- Guidetti and Claudet (2010) – Thus study evaluated fish catch rates around an MPA that was previously closed and then partially reopened under regulated co-management of the fishery in Mediterranean Sea. The 2,227-ha MPA was closed in 1991, and underwent a limited opening in 2000-2005. After a managed reopening, they found that fisher catch rates initially declined then stabilized at levels that were double the catch rates of adjacent, fully opened areas. They concluded that co-management could achieve conservation targets and fishery management goals to alleviate overfishing.
- Hilborn et al. (2004) – This synthesis paper evaluated the conditions under which marine reserves can provide improved fishery management. The paper concluded that for fisheries that are multi-species and include fish with relatively small home ranges, the use of marine reserves has advantages over traditional bag/size limits. They noted that success is highly case-specific and that understanding the spatial structure of the habitat and fish movement rates are key to success. Monitoring of fish abundance and angler effort dynamics around marine reserves is key to understanding the impacts of this management tool and its potential effectiveness.
- Callum et al. (2001) – Thus study evaluated a series of marine reserves in Florida (Merritt Island/Cape Canaveral) and St. Lucia. They found that five small reserves in St. Lucia increased catch rates of fish in adjacent open-access areas between 46-90%. They also noted increased world record catches in the Florida reserve. They concluded that marine reserves can be a key component of successful fishery management.
- Lester et al. (2009) – This synthesis paper showed that increases in fish biomass, abundance and species richness were common among marine reserves and were not an artifact of reserves being focused on best habitat. Small reserves showed significant localized benefits, and they concluded that well designed and enforced reserves can be important conservation and management tools.

Take home messages suggest that small marine reserves can have benefits in fish abundance, size structure and biomass, but the effects of reserves on regional fishing effort dynamics is a key uncertainty that will ultimately influence the outcome for management.

A Florida example of managing fisheries habitat use

Many fisheries management actions are ubiquitous across the country and even the world—things like size limit, bag limit, and harvest seasons. Others are unique to certain areas. One that is especially prevalent in Florida is "pole and troll" or no-motor zones. These are spatial regions where the possession and/or use of outboard motors are restricted. Examples are detailed above in Part 2. These are almost always implemented to (i) protect rare animals (like manatees), (ii) protect sensitive habitats like seagrass, or (iii) ensure the security of sensitive military and government operations.

Initially, it might seem obvious that a no-motor zone would decrease marine fishing demand, since so many Florida recreational fishers use motorized vessels to fish. However, these zones can create additional opportunities. The absence of fast and loud outboards, along with the props they use and wakes they produce, can be a boon to aquatic habitat like seagrasses. It may cause birds and other wildlife to more frequently use areas. There is anecdotal evidence it could even improve the fishing. If the absence of in-use outboards scares less fish, those there may feed more actively or spook less (no "run and bump", where fishers locate schools of fish by running on plane until they disturb or "bump" them). Indirect effects might occur if the zone results in better aquatic habitat, which could increase local fish abundances or densities (either by attracting fish to forage or by increasing areas for juveniles to recruit). And then there could be feedbacks. It's possible that the initial decrease in effort could lead to greater abundances or sizes of fish available for capture. It's even possible that all these things combined (more and/or larger fish, more actively feeding fish, less obnoxious behavior from other anglers), could result in even more effort than was there originally. This might seem counterintuitive, but it is possible. A no-motor zone might actually mean more fishers could effectively fish an area, since each would not disturb fish as much, and potentially would allow for greater numbers of boats to use an area before it "fishes" like it's overcrowded. The potential result of greater fishing effort from a restriction in how people operate their boats is far from guaranteed. There would certainly be people who would dislike it—people whose satisfaction utility would decrease. It's just possible that they might be partially or even wholly compensated by others who might prefer this type of managed system. For example, such fishers with larger vessels might no longer visit this area, whereas others with smaller vessels more easily controlled via trolling motor or push pole might be attracted to this area.

The point of this hypothetical is **not** to try to predict exactly what would happen. That could only be done with a series of socioecological studies and paired with quantitative modeling. The point is to make clear that it is not possible to predict, without assessing a specific fishery and surveying specific fishers, exactly how management actions will affect fishing effort, and thus the overall ecological and socioeconomic effects. In this example, if there was interest in a **potential** no-motor zone, it would be useful for managers to ensure they get a representative understanding of local and non-local stakeholders. This could include listening sessions initially, but at some point would require qualitative and quantitative surveys to assess how fishers might respond to new regulations. Then, it would benefit from scientists who build models to represent fishers and fish trying to use information about people and fish to predict likely and unlikely outcomes.

Finally, if initial research efforts suggest a favorable outcome is possible, one of the only ways to understand for sure how a change like this would affect not just fishing effort but more the ecosystem and socioeconomic system as a whole, is to actually do the experiment. This could be done as a temporary measure, like a one-year restrictive measure. However, it is absolutely critical that this type of experimental change be coupled with careful monitoring. While no-motor zones have been implemented in several other areas in Florida, publicly available reports of any pre-/post-monitoring results are scarce and normally only focus on habitat outcomes (e.g., scarring reduction) and neglect human dimensions. Reports that are available tend to be brief and preliminary but do generally indicate positive outcomes at least for seagrass scarring reduction (Thompson, 2015; Atkins, 2017). Should an experimental no-motor zone or other spatial management strategy be implemented in the St. Martin's Keys, monitoring of habitat, fish, and fishers should take place before, during and after the experimental rule. Ideally, some monitoring would also take place in at least one adjacent region. This could either act as a control (to account for changes over time, like in the cost of vessel fuel, that might by chance change with the treatment), or to monitor for spill-over effects (e.g., a redirection of boating activity) to other regions. Such an approach would allow managers to make informed decisions about what such a regulation might do in the short and long-term.

Conclusions

Part 1 explored the results of a mapping exercise to define the status of propeller scarring in the St. Martins Keys. The analysis revealed that prop scarring is severe in at least a subset of the area. This result aligns with stakeholder concerns about scarring as an issue and provides a justification to consider special management actions for at least a subset of keys. Part 2 examined the policy options available to managers and other decision makers. The policy concluded that multiple state agencies have options to enact special management actions in spatially restricted zones. Overall, FDEP possesses the most flexibility in options for management zones focused on habitat (seagrass) protection specifically, as well as statutory responsibility to do so. Part 3 explored a range of possible socioeconomic outcomes related to changes in fishing effort in response to management actions that affect fisheries regulations and/or boating access. There are a number of ways in which fishing effort can be affected by management actions. Effects on effort can be direct, where management changes directly affect how much fishing takes place. Indirect effects are more common and include where management changes result in altered fish populations or fishing areas, which in turn affect fishing. And then there can be effort feedbacks, where any of these changes in effort affect fish populations or fishing conditions (e.g., crowding) or both, which then affects future effort. In all, this can make it hard to predict how a management change can be expected to affect recreational fishing effort.

Still, there are some things managers and stakeholders can be reasonably sure of:

(1) Predicting the total effects of a recreational fishery management action on local fishing effort is not easy. Studies show the results the same type of action (e.g., changing harvest regulations) may increase or decrease effort depending on the species and system. What we are most sure of is that we can't make a confident prediction about how altering harvest or motor operation regulations around the St. Martins Keys would affect fishing effort in Citrus County—at least without more research.

(2) There are at least two ways to get more specific predictions for how fishing effort might change with a management option. The first is to survey people and assess what their stated responses to hypothetical management actions would be. These are often done with something called stated preference choice experiments. The second is to experimentally implement a policy and monitor the effect. In this case, this might look like trying a regulation for a period and carefully monitoring fishing effort in Citrus (and potentially surrounding counties). The first option (survey) will take some time and money, may not perfectly predict what will happen (because sometimes people say they will do something different than what they actually do), but would give some information that could be incorporated into the management decision making process. The second option is more likely to show what will occur, but may risk negative or unintended consequences for the socioeconomic and/or ecological system.

(3) The total effort responses are not likely to be extreme because the feedback processes in recreational fisheries often even things out more than they exacerbate them. For example, if a management change initially caused a strong decrease in effort, this would likely diminish harvest and result in locally greater catch rates, which in turn would eventually lead to some increase in effort as the better fishing attracts anglers back, or different people in. And initial increases in effort tend to decrease if they result in greater harvest and declining catch rates. However, these dynamics can be quite slow if they depend on fish population recovery (fish, especially long-lived ones, can almost always be depleted much faster than their populations can be rebuilt). This "evening out" also may not happen at all if this system shifts to an alternative stable state—which is probably most likely to occur when habitat-forming organisms like seagrass, mangroves, oysters, or salt marsh habitat are seriously degraded. What this means is that management actions that alter effort because of angler satisfaction unrelated to fish populations (e.g., facilities, boat operation, etc.) are likely to have somewhat softer or shorter-term effects on effort than those affecting fish populations directly. It also suggests it may be worth being especially protective when making management decisions about resources that experience alternative stable states, like seagrass, oysters, or salt marshes.

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Appendix A: Methods

Field work and propeller scar mapping

Study area

Propeller scar mapping was conducted within a ~2400 acres aera in the southwestern region of St. Martins Marsh Aquatic Preserve (Figure A1). Within this mapping area, four subregions (North, South, East, West) and six zones within each subregion were demarcated for the purpose of establishing UAV flight lines (Figure A2).

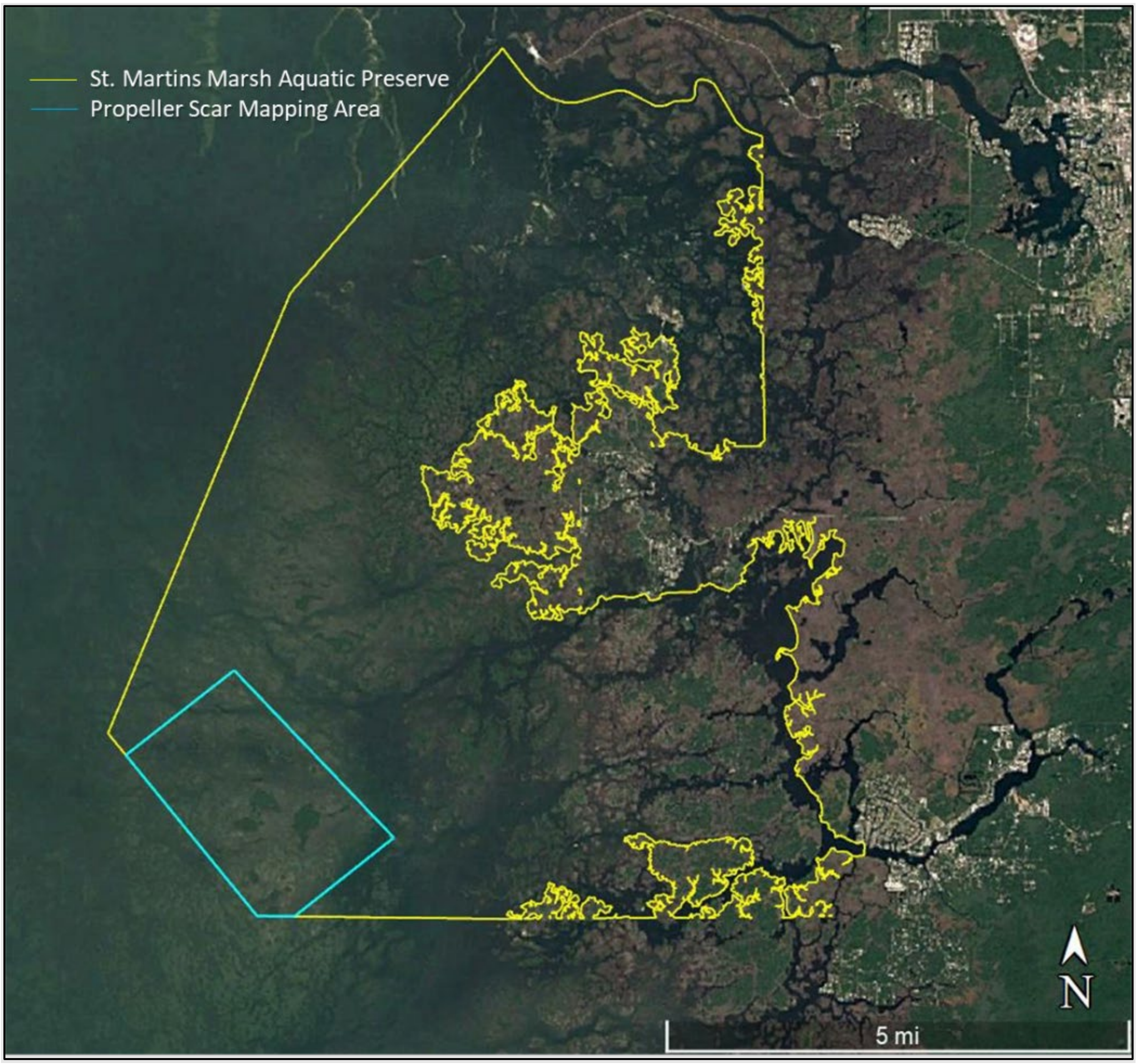


Figure A1. *Propeller scar mapping area within the St. Martins Marsh Aquatic Preserve.*

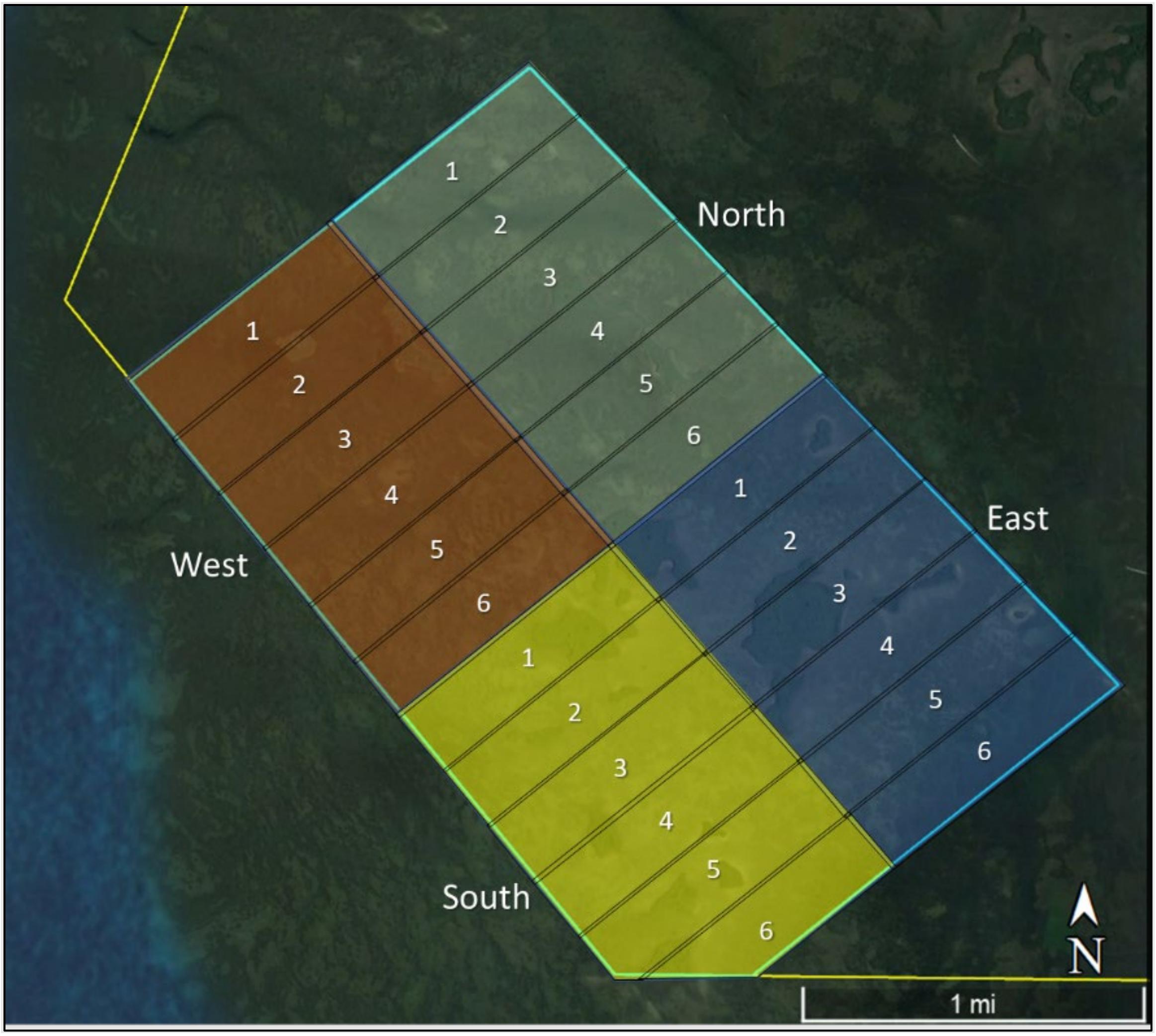


Figure A2. *Partitioning of propeller scar mapping area into four subregions and six zones within each region for the purpose of establishing UAV flight lines.*

Flight planning and mission implementation was conducted using DroneDeploy version 2.132.0, a web-based software operated on an iPad Pro running IOS version 14.8. UAV flightlines for each 100-120 acre zone were developed in DroneDeploy based on the following parameters: altitude 394 ft., image front overlap 75%, image side overlap 80%, flight line direction -41°, gimble angle -90°, and camera FOV 84° (Figure A3).

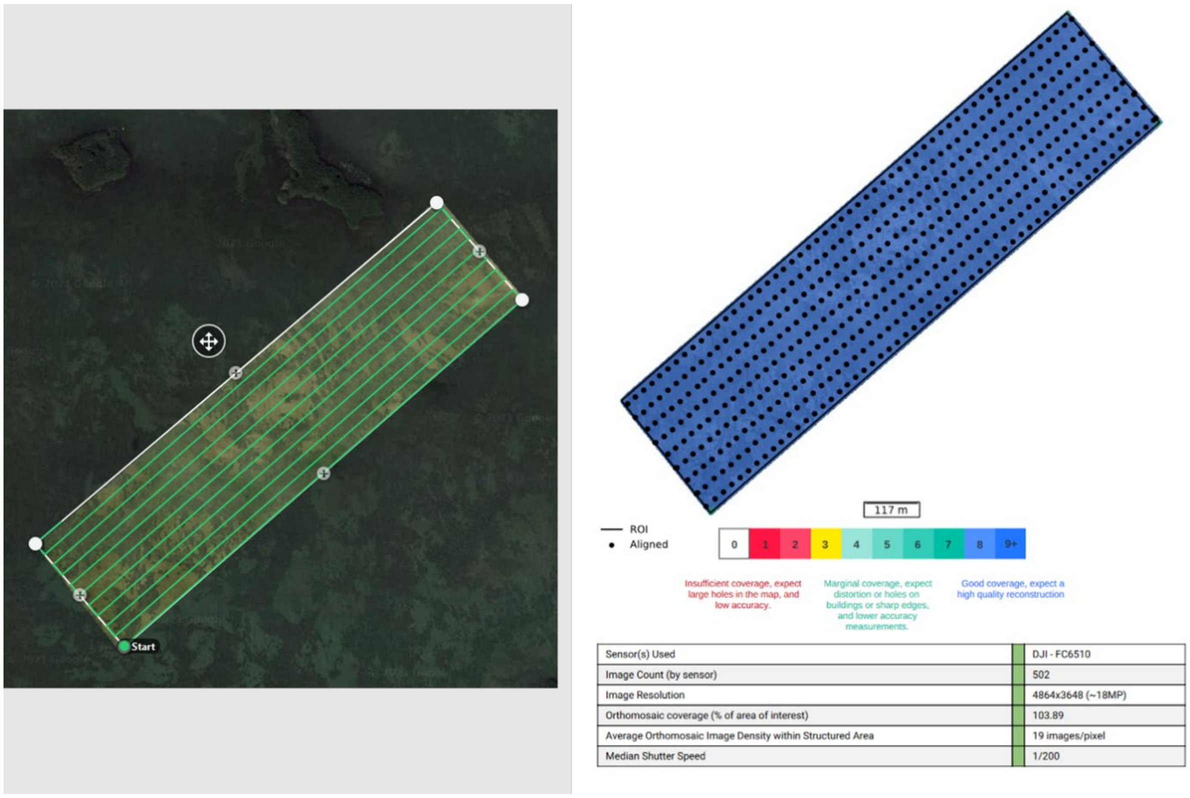


Figure A3. *Flight lines generated in DroneDeploy (left) for one zone and resulting image capture locations and coverage quality after image post processing (right).*

Image acquisition

Imagery was acquired using a DJI Matrice 200 V1 quadcopter with gimbled Zenmuse X4S camera. The Zenmuse X4S camera has a 1 inch Exmor R CMOS sensor that creates a 20 megapixel image with focal length of 8.8mm and 84° FOV. It also uses a mechanical leaf shutter to minimize electronic "rolling shutter" distortion. Missions were flown at an altitude of 394 ft (120m), which results in a ground sampling distance (resolution) of 1.33 in/px (3.54 cm/px). Camera white balance was typically set to "sunny" conditions or with a fixed ISO of 200 and auto white balance if there was any cloud cover present.

Mapping flights were conducted over a 2.5 week period in 2021 on 4/22, 4/26, 4/27 and 5/9. Flights were generally conducted on clear sky, low wind (<10kt) days between 8:30-11:00 and 15:30-17:00 when sun angle was between 25° and 60° to minimize sun glare.

UAV deployment and recovery was conducted off the bow of a 21' center console skiff that had been modified with a 4'x 7' ft flat landing platform (Figure A4).

Figure A4. Deployment and recovery platform for UAV during propeller scar mapping missions.

Image postprocessing

After images were acquired for each zone, they were uploaded to DroneDeploy and processed into a composite georeferenced orthomosaic image. Image acquisition in each zone consisted of 475 to 625 images that were stitched together using common tie-points among overlapping images. The resulting composite image for each zone was then exported from DroneDeploy as a tiled GeoTIFF file at a resolution of 2 in/px in EPSG 3857 (Web Mercator) map projection. Tiled files could then be shared as .kmz files and imported into Google Earth Pro.

Propeller scar identification and delineation

Four types of scaring were identified in UAV imagery: “light”, “dark”, “hardbottom” and “airboat”. Each of these classifications is based on the spectral reflectance of the linear feature and the type of bottom community within which the feature occurs. Each of the scaring types is defined in Table A1 and illustrated in Figures A5-A8.

Interpretation and delineation of propeller scars on each tiled image was conducted visually by 8 “delineators”. Training for delineators was implemented using written documents and a training video (see Appendix B). After viewing the video and becoming familiar with the delineation process, each perspective delineator was given a “calibration tile” to test their ability to identify and trace propeller scars within the image. Results of their delineation were compared to a reference delineation of the same tile by three reference delineators. If the perspective delineator’s assessment was within a 95% similarity of both type and scar length, the perspective delineator was allowed to begin assessing other tiles within the mapped area. If the perspective delineator’s assessment was not within an acceptable similarity, they were given a second (different) calibration tile to assess. Those results were again compared to the reference delineators assessment of the same tile. If results were within 95% similarity, then the perspective delineator was allowed to begin analyzing other tiles, if not, they were given one final chance with a new calibration tile. If the perspective delineator was unable to match a 95%

similarity after the third calibration tile, they were no longer considered eligible to participate in the propeller scar delineation process.

Table A1. *Scaring categories observed in aerial imagery and used to define scar type during assessment.*

Scar type	Description
Light	Scars in seagrass that are light in color relative to adjacent spectral signature. The bright or light spectral signature of these scars relative to adjacent dark seagrass suggest boat contact has exposed underlying mineral sediment. (Figure 5)
Dark	Scars in seagrass that are dark in color relative to the adjacent spectral signature. These scars were common in imagery and suggest interaction of boat propeller with the seagrass, but not so deep as to expose the underlying mineral substrate. (Figure 6)
Hardbottom	Scars in hardbottom communities that are lighter in color than adjacent spectral signature. These scars represent areas were macro algae and potentially other attached benthic organisms such as sponges have been dislodged by the propwash and potentially direct contact with prop and lower unit resulting in a lighter signature of the mineral bottom being expressed relative to adjacent areas. (Figure 7)
Airboat	Wide (6-8’) and uniform deviation in spectral signatures typically in seagrass areas. (Figure 8)

Figure A5. *Examples of light scars (arrows) and several dark scars (no arrows)*

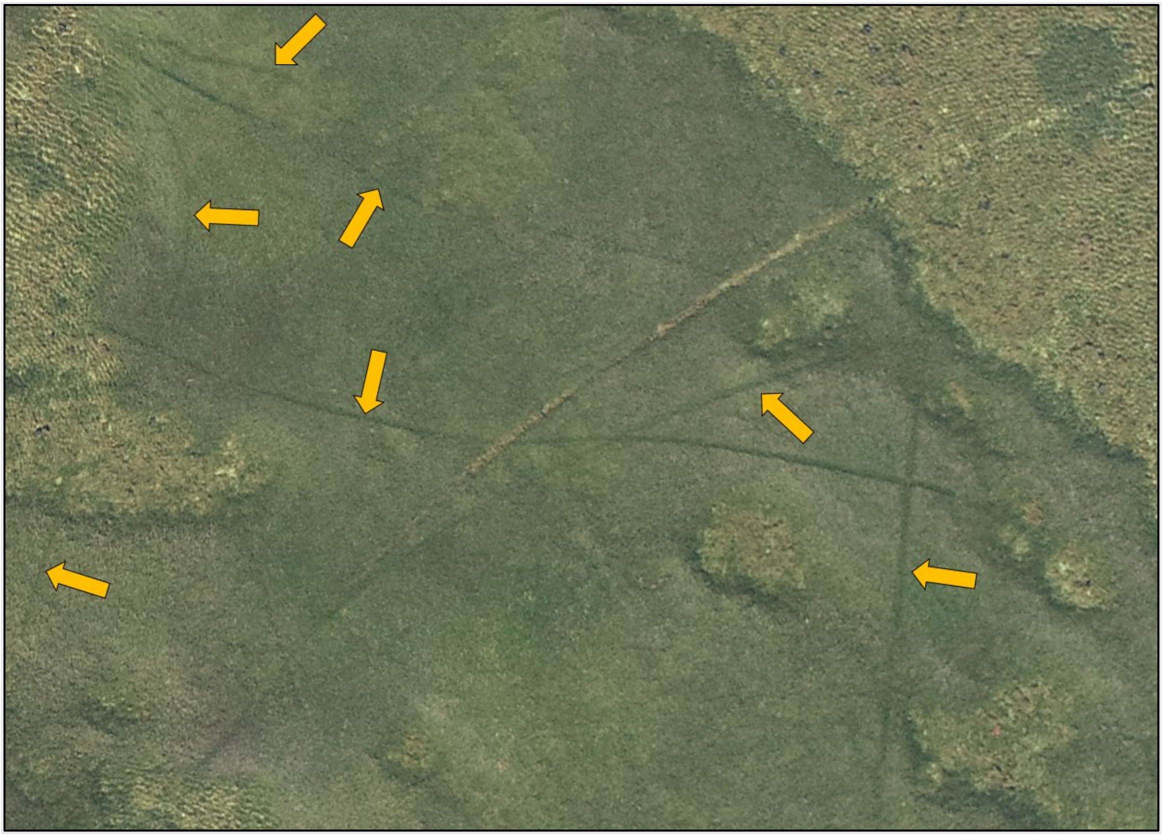


Figure A6. *Examples of dark scars (arrows) and one prominent light scar partially filled with macro algae transitioning into a hardbottom scar (no arrows).*

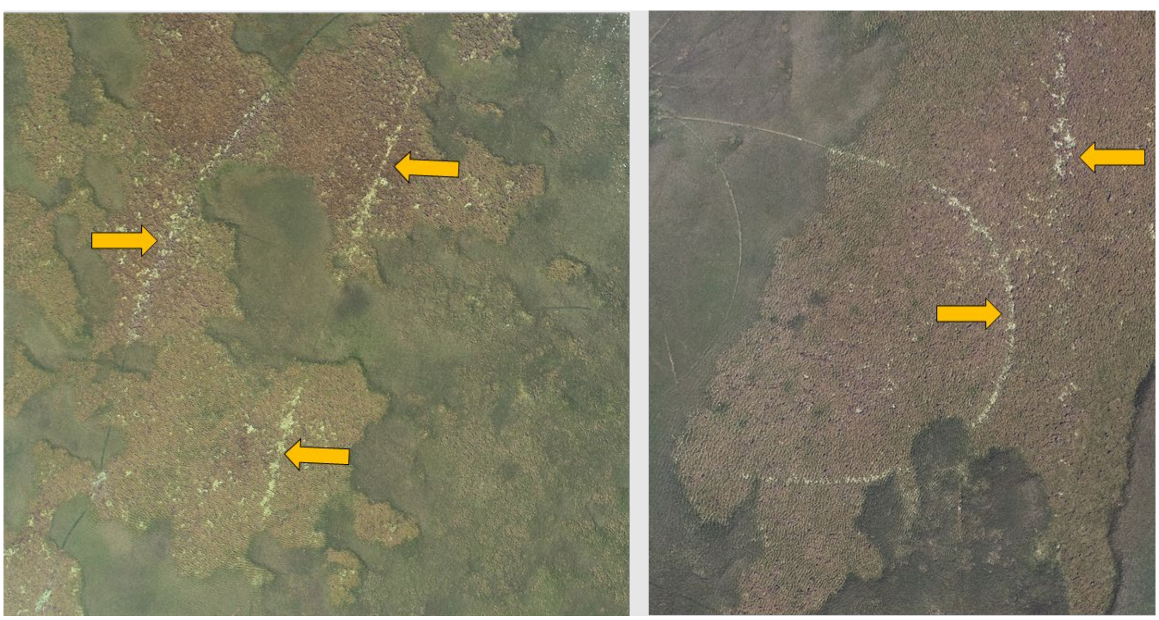


Figure A7. *Two images with examples of hardbottom scars.*

Figure A8. *Example of airboat "scars" identified in zone 1 of the southern region of the mapping area.*

Once a perspective delineator had met the calibration tile QAQC, delineators would upload a tile generated in DroneDeploy to Google Earth Pro. They would then identify a scar, trace the scar using the "add path" feature and color code the line according to the scar type. White for light scars, green for dark scars, orange for hardbottom scars and yellow for airboat scars (Figure A9). After the delineator finished tracing all identifiable scars in a tile, the traced tile would be emailed as a .kmz or .kml file to be uploaded into ArcGIS.

Figure A9. *Example of a tile that has been delineated and traced. White lines delineate light scars, green lines delineate dark scars and orange lines delineate hardbottom scars.*

Determining average width of propeller scars

To determine the average width of each type of propeller scar, tiles within the area of highest image quality, mostly in the north and west subregions, were randomly chosen and a maximum of 10 scars of each type were randomly selected until 100 measurements were made. For each scar selected, a width measurement was made at 1/3 the overall length of the scar measured from the northern or western most end of the line delineated for that scar. The average value of 100 scar widths measured for each scar type was then used to calculate aera coverage.

Spatial analysis of propeller scars in ArcGIS

In ArcMap 10.2, .kml files were converted to shapefiles and added as layers to a project. Once all tiles had been added they were grouped into their original flight zones. Since flight zones were intentionally overlapped, any tiles that overlapped were clipped to prevent any duplication of propeller scar tracings.

After all zones were clipped, flight zones were compiled into a single shapefile and categorized by each of the four scar types. Each of the 24 keys within the propeller scar mapping area were delineated by creating polygons around the edge of each key and then assigning either the key's existing name or a numeric identifier (Figure A10).

Figure A10. *Demarcation and nomenclature of keys within the propeller scar mapping area.*

Buffers were created around all keys at 100-foot intervals up to 600 feet. The propeller scar shapefile was then clipped within each of the buffer zones, creating a separate shapefile for each of the propeller scar types within each buffer zone. This output represented total propeller scars within 100, 200, 300, 400, 500, and 600 feet of all key areas respectively. In ArcMap, statistics were run on each of these outputs, to determine total linear feet of each scar type within the buffer zones. Buffers were then created around each of the 24 keys separately by dissolving the overlap so that propeller scars within the buffer zones of each key could be determined.

Spatial variability of propeller scars was determined by placing a 1-acre fishnet grid over the project area. The clipped, dissolved shapefile of propeller scars was joined with the fishnet grid which attributed the propeller scar length to each fishnet grid cell. The areas of the keys were removed from the fishnet using the erase tool and the fractional acreage of each cell was calculated. The total linear length of propeller scars per acre was calculated and the cells were classified and colored into 10 equal categories of linear feet per acre.

To try and compare spatial variability of propeller scars in this study with those in the Wood 2018 survey, propeller scar densities in each one-acre fishnet cell were reclassified into three categories, 0-400 linear feet/acre (light scarring), 400-800 linear feet/acre (moderate scarring), and 800+ linear feet/acre (severe scarring). These categories roughly correspond to a calibration analysis of at least five light, moderate and sever scarring polygons identified by Wood where propeller scars within those polygons were traced in a manner similar to this study and the linear feet of propeller scar per acre within each polygon was determined. The minimum length/acre of scar found in severe polygons determined the 800 liner feet/acre break between moderate and severe scarring. The midpoint between 0 and 800 was used to differentiate between light and moderate scaring since no quantitative difference was found between these two categories during the calibration assessment (Table A2).

Table A2. *Results of propeller scar tracing within polygons designated by WOOD in 2018 study. Number of propeller scars within at least five polygons of each category were delineated and used to determine the breakpoints between the three categories of propeller scar severity.*

Scaring severity defined by WOOD	Delineated propeller scar density, liner feet/acre				
	min	max	median	average	St Dev
light	164	723	496	481	197
moderate	157	951	423	499	318
severe	800	2219	1275	1421	524

Literature reviews and policy research

Relevant literature and state reports were reviewed and included 1) those related to marine protected areas, particularly inshore and those with goals of creating unique fishing opportunities, 2) effects of spatially explicit and policy differentiated management approaches on angler and boater behavior, and 3) Florida Administrative Code, state statutes, and other policy documents related to i) boating law and regulation, ii) sovereign submerged lands and Aquatic Preserve management, and iii) fisheries law regulation in Florida, and elsewhere.

Appendix B: Training Information for Propeller Scar Delineators

Link to propeller scar delineation training video

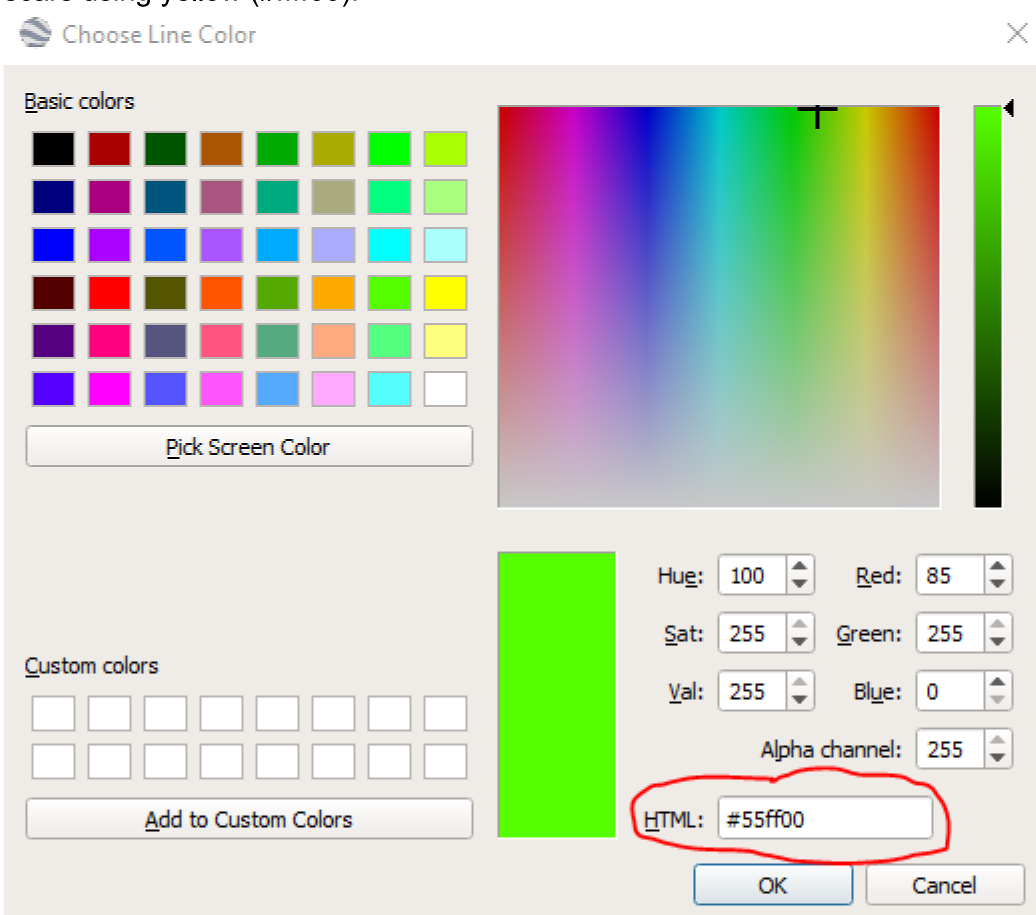
https://mediasite.video.ufl.edu/Mediasite/Play/e1350a44070d4067998d372fd3b9064b1d.

Guidance for Prop Scar Assessment Using Google Earth Pro

1. Download Google Earth Pro
   https://www.google.com/earth/download/gep/agree.html?hl=en-GB
2. Download the KMZ image file(s) provided and extract images to an empty folder on your computer.
3. From Google Earth Pro, select "file" then "open" and navigate to the folder where you extracted the image files and choose a file from the list. The list will only show .kml files.
4. After opening, the KML file image should appear on the screen and be listed under your "Temporary Places" folder in Google Earth Pro directory.
5. If you cannot see or find the image, double click on the file name you just uploaded, and the screen should zoom over to that location. Zoom in as necessary to scan the image and look for any prop scars.
6. If the square or rectangle image is skewed on the screen and appears more like a rhombus, press the letter "u" once and the image will reorient to nadir perspective. Use this key whenever you feel the image is becoming oblique.
7. Make sure the file name linked to the image is highlighted under temporary places and select the "add new path" icon in the menu at the top of the screen or use the keyboard shortcut (ctl + shift + T).
8. Starting with light colored seagrass scars, scan the image for any prop scars, when you find one, position the cursor at one end of the prop scar and click once. Ensure the scars are being traced in white (this is the default). Move the cursor along the prop scar and click as you go so that the line path overlays the prop scar. If the prop scar is straight, you will only have to click once at the beginning and again at the end. If the prop scar is curved, you will need to click multiple times along the path to keep the line within the path. You can also hold the left mouse button down continuously as you trace the prop scar, but that will make multiple points that can be hard to undo if you make an error and it is often more difficult to control the cursor.
9. Before clicking "ok" on pop up window, double check that the line you drew is overlaying the prop scar. If it is not, or one or more points are significantly outside the actual scar, move your cursor near the dot that you would like to correct, and it will turn green. Once green, left click and hold the mouse button and adjust the position of the dot to a better location.
10. When you are finished tracing that prop scar, click "ok" on the pop-up window. A new entry called "untitled path" should appear in the Temporary Places directory under the image file name. We do not need a name for each path, but make sure the entry is located below and indented relative to the KML image file. If for some reason it is in the wrong location you can right click on the "untitled path", "cut", then move the cursor to

the desired image file name, right click and “paste”. That should move the “untitled path” file under the correct image folder. If this happens repeatedly double check that the correct image file name is highlighted when you start tracing a new prop scar.

11. Once that trace/path is competed, look for another prop scar, select the “add new path” icon again or use the keyboard shortcut (ctl + shift + T) to draw another line. Continue this process until all light colored prop scars have been traced on the image.
12. Once you have traced all the light seagrass prop scars in the image, move on to dark seagrass scars. For the first dark scar, make sure the color is changed to lime green. You change the color by using the “Style, Color” tab on the pop-up box that opens when you select “add Path”. The color selection box opens when you double click on the white swatch next to color. To make sure we are all using the same color of green, please use color code #55ff00 in the HTML color selection box (see picture below). If there are hardbottom scars, trace them next using orange (#ffaa00) and finally trace any airboat scars using yellow (#ffff00).



13. Once all types of scars are traced, right click on the KML image file in “temporary places” (it has the blue striped sphere at the beginning of the name) and select “email” and direct the email to clarkmw@ufl.edu.
14. Before you load the next image, right click on the Temporary Places folder, and select “Delete Contents”. This will remove any files from the previous tracing effort. If you want to save any (or all) of the files in the temporary places folder you can right click on an individual file or the main image and either “Save to My Places” or “Save Places As”. If you choose “Save to My Places” it will move the files up into the more permanent “My

Places” folder on Google Earth Pro. If you choose “Save Place As”, the files will be placed wherever you direct them on your computer.

15. Now you can open another image to digitize or request another set of images to download and work on.

Propeller Scar Tracing Quick Reference Sheet

Preparing your workspace:

Identifying and tracing propeller scars can be tedious and often relies on subtle differences.

Having a good workspace to conduct your delineation is critical to success. Here are a few tips

- Use a large, high-resolution screen whenever possible
- Make sure there is no glare on the screen
- Dim the lights in the room and move away from windows if there is too much ambient
- light.

Reminders:

- When tracing propeller scars, make sure any line paths added are being entered in the directory under the image file name you are working on in Temporary Places,
- When tracing a propeller scar, it is often easier and more accurate to use a mouse and click at specific points along the path of the propeller scar than to try drawing a continuous line. Just make sure to click enough points along the radius of a curved propeller scar to keep the tracing line within the boundary of the scar. Adjust the line if necessary.
- Zoom in and out of the image to reveal more detail when necessary.
- Use the up, down, left and right directional keys to move the image as necessary while tracing a scar. When zoomed in, many scars will extend beyond the edge of the screen. Make sure to keep the tracing contiguous if the propeller scar is contiguous.
- The color codes for the four types of scars are:
  "light" scar, trace in white (HTML: #ffffff)
  "dark" scar, trace in lime green (HTML: #55ff00)
  hardbottom scar, trace in orange (HTML: #ffaa00)
  airboat scar, trace in yellow (HTM: #ffff00)
- Terminate scar tracing at the ends of a clearly visible scar or at the edge of image.
- Scars may be intermittent with undisturbed areas along the overall path of vessel. Only mark scars that are clearly visible and make sure to change color if scar transitions from one type to another.
- Scars only occur in areas where the surrounding area is dark. If the surrounding area of a linear feature is light in color, it is not a propeller scar.
- Scan the image methodically, typically from upper left to lower right while zoomed in. Once you think you have identified and traced all of the propeller scars, scan the image on last time before submitting.
  If you find an issue with imagery, if the image is not clear or if found something significant you would like to convey, add a brief message to your email when sending the completed tile tracing.
- Make sure to email the finished tile in even if there are no propeller scars on it.

Shortcuts:

- Use the “u” key to reorient the image in Google Earth Pro to nadir orientation.
- Keyboard short cut for “add path”. Press (Control + Shift+ T).
- To move image up, down, right, or left use the direction arrow keys on your keyboard.
- To remove a point on your tracing line, place the cursor on a dot on the line and right click the mouse

Appendix C: Propeller Scarring Detailed Results Tables

Table C1. *Linear feet, aerial coverage and density of light scars within the 0-100’, 0-200’, and 0-300’ buffer widths around each key.*

	0-100’ buffer				0-200’ buffer				0-300’ buffer			
Key ID	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)
1	3,705	4,508	755	918	14,453	17,586	1,304	1,587	25,472	30,994	1,364	1,659
2	3,017	3,671	303	368	10,262	12,487	489	595	15,119	18,397	454	552
3	744	905	80	97	2,658	3,234	134	163	3,864	4,702	123	149
4	623	758	48	58	3,133	3,812	117	142	6,212	7,559	149	182
5	133	162	32	39	1,111	1,352	115	140	2,373	2,887	143	174
6	738	899	57	70	1,765	2,148	70	85	2,662	3,239	70	85
7	0	0	0	0	30	37	3	4	165	201	11	13
8	130	158	47	58	288	351	42	51	471	573	42	51
9	0	0	0	0	228	277	11	14	608	740	19	24
10	27	33	10	12	195	237	31	38	284	346	27	33
11	29	36	24	29	250	304	64	78	517	630	65	79
12	314	382	86	105	979	1,192	113	137	1,784	2,171	118	143
13	831	1,011	56	68	2,690	3,273	94	115	4,664	5,675	108	131
14	484	588	204	248	1,319	1,605	214	260	2,915	3,547	270	328
15	76	92	10	12	235	286	16	19	681	829	29	35
16	471	573	84	103	1,274	1,550	102	124	2,403	2,923	115	140
17	660	803	111	135	948	1,153	73	89	1,127	1,372	53	64
18	0	0	0	0	191	232	23	27	390	475	26	32
19	180	220	42	51	577	702	58	70	2,577	3,136	151	184
20	966	1,175	162	197	1,648	2,006	125	152	2,442	2,972	112	136
21	214	260	38	47	818	996	75	91	1,205	1,466	72	88
Crawl Key	420	512	49	60	2,007	2,442	110	133	4,361	5,307	148	180
Green Key	0	0	0	0	501	610	88	108	882	1,073	83	101
Sand Key	1,039	1,264	182	222	2,905	3,535	228	278	3,891	4,735	184	224
Total	14,800	18,008	2,381	2,897	50,465	61,406	3,698	4,499	87,070	105,947	3,935	4,788

Table C2. *Linear feet, aerial coverage and density of light scars within the 0-400’, 0-500’, and 0-600’ buffer widths around each key.*

	0-400’ buffer				0-500’ buffer				0-600’ buffer			
Key ID	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)
1	32,740	39,838	1,181	1,437	38,408	46,735	1,006	1,224	44,169	53,745	1,073	1,306
2	20,234	24,621	430	523	25,440	30,955	410	498	29,411	35,787	456	554
3	4,992	6,075	113	137	6,369	7,750	109	133	8,157	9,926	135	164
4	8,550	10,404	149	181	10,773	13,108	145	177	12,691	15,442	167	203
5	4,487	5,460	180	219	6,322	7,692	182	221	7,963	9,689	215	261
6	3,643	4,432	70	85	4,472	5,442	65	79	5,345	6,504	75	91
7	343	418	17	20	705	858	26	31	1,225	1,491	43	52
8	661	805	44	53	956	1,164	49	59	1,471	1,790	71	86
9	1,191	1,449	27	33	1,744	2,122	30	37	2,481	3,019	42	51
10	466	567	30	36	1,124	1,368	50	61	1,597	1,943	64	77
11	781	951	58	70	1,032	1,256	51	62	1,260	1,533	55	66
12	2,371	2,885	103	125	2,990	3,638	92	112	3,592	4,371	103	126
13	5,804	7,063	98	119	7,605	9,253	99	120	9,829	11,960	125	152
14	3,966	4,825	245	298	5,076	6,177	230	280	5,734	6,977	245	298
15	1,536	1,869	46	57	2,112	2,570	49	59	2,772	3,372	62	75
16	3,378	4,111	113	137	4,056	4,935	101	122	4,454	5,420	104	126
17	1,249	1,520	40	49	1,654	2,013	39	47	1,758	2,140	39	47
18	512	623	23	28	734	894	24	29	936	1,138	28	34
19	3,773	4,590	153	186	4,092	4,979	124	151	4,835	5,883	137	167
20	3,366	4,096	108	131	4,047	4,924	98	120	4,635	5,640	108	132
21	2,142	2,606	93	114	2,460	2,993	85	103	2,821	3,432	99	120
Crawl Key	7,175	8,730	171	208	9,707	11,811	176	214	12,462	15,164	219	266
Green Key	1,164	1,417	71	87	1,435	1,746	64	78	1,940	2,360	81	98
Sand Key	4,801	5,841	162	197	5,174	6,295	135	165	5,545	6,747	142	173
Total	119,325	145,195	3,723	4,530	148,486	180,678	3,439	4,185	177,082	215,474	3,886	4,728

Table C3. *Linear feet, aerial coverage and density of light scars within the 0-700', 0-800', and 0-900' buffer widths around each key.*

	0-700' buffer				0-800' buffer				0-900' buffer			
Key ID	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)
1	49,203	59,870	776	944	53,147	64,670	679	827	57,765	70,288	612	744
2	33,764	41,084	350	426	38,017	46,259	329	400	42,743	52,009	314	382
3	10,259	12,483	114	138	12,019	14,624	111	135	13,019	15,841	102	124
4	13,890	16,902	124	151	15,536	18,905	117	142	17,799	21,658	114	139
5	9,422	11,465	169	206	10,999	13,384	165	201	12,179	14,819	155	189
6	6,593	8,022	62	75	8,777	10,680	69	84	10,728	13,053	72	88
7	1,586	1,930	37	45	1,997	2,430	37	45	2,789	3,394	42	51
8	1,725	2,099	54	66	1,939	2,359	49	60	2,250	2,738	48	58
9	3,523	4,287	40	49	4,553	5,540	43	53	5,107	6,214	41	50
10	2,449	2,980	61	75	2,912	3,543	59	72	3,724	4,531	63	76
11	1,589	1,933	45	55	1,960	2,385	46	55	2,551	3,105	50	60
12	4,272	5,198	80	97	5,089	6,192	78	95	5,684	6,916	73	89
13	11,297	13,747	97	119	13,043	15,871	95	116	14,671	17,852	92	112
14	6,722	8,179	187	228	7,577	9,220	169	206	8,767	10,668	159	193
15	3,649	4,440	55	67	4,338	5,279	54	66	4,866	5,922	51	62
16	5,709	6,946	87	106	6,923	8,424	86	105	8,247	10,035	85	104
17	1,989	2,420	29	35	2,264	2,754	27	32	2,883	3,508	28	34
18	1,230	1,497	24	29	2,367	2,881	37	45	3,306	4,023	43	52
19	5,319	6,472	97	118	6,456	7,856	95	115	7,389	8,991	88	108
20	4,967	6,044	77	94	5,538	6,739	71	86	6,577	8,003	70	86
21	3,278	3,989	80	97	4,774	5,810	99	120	5,761	7,010	102	124
Crawl Key	15,632	19,021	187	228	18,388	22,375	189	230	20,895	25,425	187	227
Green Key	2,862	3,483	78	95	3,620	4,404	81	99	4,551	5,537	85	104
Sand Key	5,593	6,806	98	119	5,847	7,114	87	106	6,095	7,417	78	95
Total	206,521	251,295	3,009	3,662	238,081	289,697	2,871	3,494	270,345	328,956	2,754	3,351

Table C4. *Linear feet, aerial coverage and density of light scars within the 0-1000' buffer widths around each key.*

	0-1000' buffer			
Key ID	**length (ft)**	**area (ft^2)**	**density (ft/ac)**	**density (ft^2/ac)**
1	60,768	73,942	548	666
2	50,004	60,844	316	384
3	13,819	16,815	93	113
4	20,003	24,339	113	137
5	14,615	17,784	161	196
6	12,535	15,253	74	90
7	3,396	4,132	42	52
8	3,004	3,655	53	64
9	6,247	7,602	43	53
10	4,626	5,629	64	78
11	3,184	3,874	51	63
12	6,393	7,779	69	84
13	16,940	20,613	92	112
14	10,111	12,304	151	184
15	5,999	7,300	54	65
16	9,215	11,213	80	98
17	3,659	4,453	31	37
18	4,434	5,395	48	58
19	8,068	9,817	80	98
20	7,766	9,450	71	86
21	6,481	7,887	99	120
Crawl Key	22,554	27,443	179	217
Green Key	5,262	6,403	84	102
Sand Key	6,754	8,219	76	92
Total	305,838	372,144	2,670	3,249

Table C5. *Linear feet, aerial coverage and density of dark scars within the 0-100', 0-200', and 0-300' buffer widths around each key.*

	0-100' buffer				0-200' buffer				0-300' buffer			
Key ID	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)
1	1262	1092	257	222	4194	3630	378	328	7759	6715	415	360
2	834	722	84	72	2493	2158	119	103	3672	3178	110	95
3	0	0	0	0	185	160	9	8	314	272	10	9
4	90	78	7	6	394	341	15	13	815	706	20	17
5	0	0	0	0	27	23	3	2	481	416	29	25
6	635	550	49	43	831	719	33	28	1000	866	26	23
7	40	35	8	7	78	67	8	7	78	67	5	4
8	0	0	0	0	0	0	0	0	0	0	0	0
9	146	126	15	13	409	354	20	18	492	426	16	14
10	0	0	0	0	168	146	27	23	304	263	29	25
11	0	0	0	0	109	94	28	24	332	288	42	36
12	81	70	22	19	196	169	23	20	400	346	26	23
13	111	96	7	6	386	334	14	12	787	681	18	16
14	14	12	6	5	62	54	10	9	88	76	8	7
15	17	15	2	2	140	121	9	8	366	316	16	13
16	293	253	52	45	577	500	46	40	1112	963	53	46
17	0	0	0	0	102	89	8	7	102	89	5	4
18	0	0	0	0	39	34	5	4	158	136	11	9
19	0	0	0	0	119	103	12	10	248	215	15	13
20	18	16	3	3	18	16	1	1	165	143	8	7
21	5	4	1	1	110	95	10	9	110	95	7	6
Crawl Key	575	498	67	58	1140	986	62	54	1810	1566	61	53
Green Key	29	25	14	12	81	70	14	12	131	113	12	11
Sand Key	114	99	20	17	643	557	51	44	814	705	39	33
Total	4,264	3,690	615	532	12,501	10,820	904	782	21,538	18,641	979	848

Table C6. *Linear feet, aerial coverage and density of dark scars within the 0-400', 0-500', and 0-600' buffer widths around each key.*

	0-400' buffer				0-500' buffer				0-600' buffer			
Key ID	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)
1	11600	10039	419	362	14824	12830	388	336	17427	15083	301	261
2	4618	3997	98	85	5745	4972	92	80	6852	5930	76	65
3	602	521	14	12	1017	880	17	15	1424	1233	17	14
4	1335	1156	23	20	1609	1393	22	19	1618	1401	15	13
5	581	503	23	20	678	587	20	17	947	819	18	16
6	1124	973	21	19	1325	1146	19	17	1552	1343	15	13
7	78	67	4	3	125	108	5	4	189	163	5	4
8	38	33	3	2	109	94	6	5	303	262	10	9
9	723	626	17	14	1012	876	18	15	1398	1210	17	15
10	332	288	21	18	778	673	35	30	816	706	23	20
11	593	513	44	38	935	809	46	40	1083	937	33	29
12	591	512	26	22	820	710	25	22	1362	1179	28	24
13	1112	962	19	16	1569	1358	20	18	1878	1625	17	15
14	255	221	16	14	503	435	23	20	609	527	19	16
15	424	367	13	11	687	595	16	14	733	634	12	10
16	1456	1260	49	42	1746	1511	43	37	2044	1769	34	29
17	102	89	3	3	168	145	4	3	310	268	5	4
18	158	136	7	6	158	136	5	4	158	136	3	3
19	527	456	21	18	694	601	21	18	715	619	14	12
20	281	243	9	8	456	395	11	10	456	395	8	7
21	128	111	6	5	128	111	4	4	156	135	4	3
Crawl Key	2317	2005	55	48	2723	2357	49	43	3239	2803	40	35
Green Key	165	143	10	9	301	260	13	12	417	361	12	11
Sand Key	840	727	28	25	1170	1013	31	26	1355	1173	25	21
Total	29,980	25,947	947	820	39,281	33,997	934	808	47,041	40,714	751	650

Table C7. *Linear feet, aerial coverage and density of dark scars within the 0-700', 0-800', and 0-900' buffer widths around each key.*

	0-700' buffer				0-800' buffer				0-900' buffer			
Key ID	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)
1	20956	18138	330	286	24914	21563	319	276	28856	24975	306	264
2	7971	6899	83	72	8852	7662	77	66	9869	8542	72	63
3	1727	1495	19	17	1986	1719	18	16	2204	1907	17	15
4	2056	1779	18	16	2162	1871	16	14	2352	2035	15	13
5	1154	999	21	18	1154	999	17	15	1154	999	15	13
6	1972	1707	18	16	2202	1906	17	15	2595	2246	17	15
7	223	193	5	4	361	313	7	6	647	560	10	8
8	678	587	21	18	726	628	19	16	943	816	20	17
9	2005	1735	23	20	2403	2080	23	20	2551	2208	21	18
10	856	741	21	19	912	789	19	16	1400	1211	24	20
11	1374	1189	39	34	1564	1354	36	31	1671	1446	32	28
12	1887	1633	35	31	2224	1925	34	30	2464	2133	32	27
13	2340	2025	20	17	2614	2262	19	17	2930	2536	18	16
14	694	600	19	17	821	711	18	16	951	823	17	15
15	812	703	12	11	1022	885	13	11	1208	1045	13	11
16	2593	2244	40	34	3088	2673	38	33	3301	2857	34	29
17	443	383	6	6	682	590	8	7	958	829	9	8
18	158	136	3	3	158	136	2	2	366	317	5	4
19	821	711	15	13	821	711	12	10	906	784	11	9
20	456	395	7	6	529	458	7	6	529	458	6	5
21	200	173	5	4	337	292	7	6	337	292	6	5
Crawl Key	3454	2989	41	36	3700	3202	38	33	3801	3290	34	29
Green Key	537	465	15	13	643	557	14	12	808	700	15	13
Sand Key	1488	1288	26	23	1711	1481	25	22	1946	1684	25	22
Total	56,854	49,208	845	731	65,587	56,765	804	696	74,749	64,695	773	669

Table C8. *Linear feet, aerial coverage and density of dark scars within the 0-1000' buffer widths around each key.*

	0-1000' buffer			
Key ID	**length (ft)**	**area (ft^2)**	**density (ft/ac)**	**density (ft^2/ac)**
1	32320	27973	291	252
2	11224	9715	71	61
3	2387	2066	16	14
4	2987	2585	17	15
5	1239	1073	14	12
6	2902	2512	17	15
7	772	668	10	8
8	1292	1118	23	20
9	2714	2349	19	16
10	1777	1538	25	21
11	1923	1664	31	27
12	2748	2378	30	26
13	3391	2935	18	16
14	1341	1160	20	17
15	1313	1136	12	10
16	3768	3261	33	28
17	1147	992	10	8
18	685	593	7	6
19	1009	873	10	9
20	529	458	5	4
21	337	292	5	4
Crawl Key	4079	3531	32	28
Green Key	1259	1089	20	17
Sand Key	2334	2020	26	23
Total	85,477	73,981	761	658

Table C9. *Linear feet, aerial coverage and density of hardbottom scars within the 0-100', 0-200', and 0-300' buffer widths around each key.*

	0-100' buffer				0-200' buffer				0-300' buffer			
Key ID	**length (ft)**	**area (ft^2)**	**density (ft/ac)**	**density (ft^2/ac)**	**length (ft)**	**area (ft^2)**	**density (ft/ac)**	**density (ft^2/ac)**	**length (ft)**	**area (ft^2)**	**density (ft/ac)**	**density (ft^2/ac)**
1	0	0	0	0	0	0	0	0	43	169	2	9
2	263	1036	26	104	398	1568	19	75	409	1611	12	48
3	0	0	0	0	0	0	0	0	114	449	4	14
4	113	445	9	34	118	465	4	17	118	465	3	11
5	8	32	2	8	8	32	1	3	8	32	0	2
6	0	0	0	0	26	102	1	4	26	102	1	3
7	0	0	0	0	0	0	0	0	147	579	10	39
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	84	331	6	22	84	331	3	12	108	425	3	10
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	108	425	9	34	435	1713	21	82
17	0	0	0	0	62	244	5	19	136	536	6	25
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
Crawl Key	0	0	0	0	0	0	0	0	0	0	0	0
Green Key	0	0	0	0	0	0	0	0	0	0	0	0
Sand Key	0	0	0	0	0	0	0	0	0	0	0	0
Total	468	1,843	43	168	804	3,166	42	164	1,544	6,081	62	243

Table C10. Linear feet, aerial coverage and density of hardbottom scars within the 0-400', 0-500', and 0-600' buffer widths around each key.

	0-400' buffer				0-500' buffer				0-600' buffer			
Key ID	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)
1	419	1650	15	60	486	1913	13	50	814	3206	64	252
2	570	2245	12	48	903	3556	15	57	1116	4396	56	220
3	249	981	6	22	549	2161	9	37	695	2737	37	146
4	204	803	4	14	317	1250	4	17	413	1627	18	69
5	8	32	0	1	39	154	1	4	142	559	12	49
6	80	315	2	6	371	1460	5	21	614	2418	28	109
7	189	744	9	36	219	864	8	32	357	1406	40	158
8	0	0	0	0	0	0	0	0	0	0	0	0
9	93	366	2	8	167	657	3	11	201	792	11	44
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	153	603	3	10	248	978	3	13	304	1197	12	49
14	0	0	0	0	27	106	1	5	27	106	4	15
15	0	0	0	0	0	0	0	0	0	0	0	0
16	435	1713	15	57	218	857	5	21	435	1713	33	129
17	136	536	4	17	136	536	3	13	68	268	5	19
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
Crawl Key	0	0	0	0	0	0	0	0	0	0	0	0
Green Key	0	0	0	0	0	0	0	0	0	0	0	0
Sand Key	0	0	0	0	104	411	3	11	314	1237	26	103
Total	2,536	9,989	71	280	3,784	14,904	74	292	5,500	21,663	346	1,364

Table C11. *Linear feet, aerial coverage and density of hardbottom scars within the 0-700', 0-800', and 0-900' buffer widths around each key.*

	0-700' buffer				0-800' buffer				0-900' buffer			
Key ID	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)	length (ft)	area (ft^2)	density (ft/ac)	density (ft^2/ac)
1	1,406	5538	22	87	1,953	7690	25	98	2,662	10486	28	111
2	1,326	5224	14	54	1,503	5918	13	51	1,602	6309	12	46
3	718	2827	8	31	1,108	4363	10	40	1,218	4797	10	37
4	413	1625	4	14	432	1703	3	13	472	1857	3	12
5	213	840	4	15	341	1345	5	20	427	1681	5	21
6	723	2848	7	27	776	3058	6	24	814	3208	5	22
7	528	2079	12	48	601	2366	11	44	749	2951	11	45
8	0	0	0	0	0	0	0	0	135	531	3	11
9	584	2301	7	26	872	3433	8	33	1,576	6206	13	50
10	0	0	0	0	0	0	0	0	0	0	0	0
11	61	239	2	7	104	408	2	9	211	831	4	16
12	0	0	0	0	0	0	0	0	0	0	0	0
13	318	1252	3	11	332	1308	2	10	412	1622	3	10
14	27	106	1	3	84	332	2	7	103	406	2	7
15	0	0	0	0	0	0	0	0	83	329	1	3
16	218	857	3	13	256	1008	3	13	414	1629	4	17
17	136	536	2	8	136	536	2	6	452	1781	4	17
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	62	245	1	3	62	245	1	3
21	0	0	0	0	28	110	1	2	139	546	2	10
Crawl Key	0	0	0	0	0	0	0	0	0	0	0	0
Green Key	0	0	0	0	0	0	0	0	0	0	0	0
Sand Key	220	865	4	15	325	1279	5	19	495	1950	6	25
Total	6,890	27,137	91	360	8,912	35,102	100	393	12,025	47,364	118	464

Table C12. *Linear feet, aerial coverage and density of hardbottom scars within the 0-1000' buffer widths around each key.*

	0-1000' buffer			
Key ID	**length (ft)**	**area (ft^2)**	**density (ft/ac)**	**density (ft^2/ac)**
1	3,053	12023	28	108
2	1,923	7573	12	48
3	1,301	5126	9	34
4	743	2926	4	16
5	427	1681	5	19
6	1,121	4416	7	26
7	1,011	3981	13	50
8	147	577	3	10
9	2,279	8976	16	62
10	0	0	0	0
11	238	939	4	15
12	0	0	0	0
13	412	1622	2	9
14	115	452	2	7
15	122	479	1	4
16	586	2309	5	20
17	797	3139	7	26
18	0	0	0	0
19	0	0	0	0
20	285	1121	3	10
21	222	876	3	13
Crawl Key	0	0	0	0
Green Key	0	0	0	0
Sand Key	667	2628	7	29
Total	15,448	60,843	129	508