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When fishers ask for more protection: Co-produced spatial management recommendations to protect seagrass meadows from leisure boating

Ross E. Boucek [a,b,*], Kristin A. Anderson [a], Benjamin L. Jones [a,c], Jennifer S. Rehage [a,b]

[a] Bonefish & Tarpon Trust, 2937 SW Avenue, Suite 203, Miami, FL 33133, USA
[b] Department of Earth and Environment, Florida International University, Miami, FL, USA
[c] Project Seagrass, 33 Park Place, Cardiff CF10 3BA, UK

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ABSTRACT

Leisure boating is becoming more popular in developed societies, stressing seagrass systems. Spatial management and marine zoning, along with education, enforcement, and appropriate signage can reduce this stress. Yet, achieving conservation goals with marine zoning depends on social and organizational factors. Coproduction models that work collaboratively with stakeholders in marine zone or protected area (MPA) planning can improve conservation outcomes. The Florida Keys National Marine Sanctuary (FKNMS; U.S.) encompasses one of the largest seagrass meadows in the world, with the mission to balance marine use with conservation of natural resources. Over the last twelve years, FKNMS has experienced exponential increases in leisure boating, which is having important consequences to the functioning of its managed coastal ecosystems. Following a decade-long planning process, in 2022 FKNMS released a revised draft management plan that uses marine zoning to increase the resilience of FKNMS natural resources by reducing local stresses on the system. In the decade leading to the release of this management plan, for-hire coastal fishers worked with scientists to coproduce comprehensive marine zoning recommendations to reduce leisure boating stresses to seagrass habitats that support important fisheries. Coproduced zoning recommendations would protect 100% and 60% more seagrass and living bottom compared to the FKNMS plan. These recommendations would create an MPA network protecting two seagrass meadows that are centers of activity for important fishery species that form spawning aggregations within a seasonal no fishing MPA. This example highlights how long-term investment in coproduction can result in more comprehensive management plans supported by stakeholders.

1. Introduction

A key challenge for seagrass conservation is understanding and managing threatening activities at local scales [83]. Leisure boating is one such activity that, particularly in the presence of more widely acknowledged threats (e.g., climate change, coastal development, eutrophication), is commonly overlooked. A working definition for leisure boating is any form of marine recreation that includes the use of a vessel (both motorized and non-motorized). Leisure boating activities encompassed in this definition include both consumptive (i.e., recreational fishing) and non-consumptive activities (i.e., SCUBA diving, snorkeling, sailing, use of paddle craft, personal water craft use, etc.), as well as those entities that provide these opportunities for-hire. Threats from leisure boating, while comparatively small in impact, occur over large scales and with high frequency that they can have important consequences for seagrass ecosystems [7,22,69]. For instance, a 34% regression of *Posidonia* meadows in the Mediterranean over the last 50 years has largely been attributed to the leisure boating sector [22].

Impacts to submerged aquatic vegetation from leisure boating may include physical damage and loss via anchoring and moorings, vessel groundings, and propeller scarring [22,7], which have knock-on effects for fish recruitment [40] and carbon storage [73]. Moreover, new evidence from the Mediterranean also reveals the surprising morphological and ultrastructural impact of marine noise on seagrass plants [78]. In many high- and upper middle-income economies, outdoor recreation and leisure boating have become more pervasive over time as individuals have more time and resources [18]. Following the COVID-19 pandemic, there was a renewed interest in outdoor recreation, further increasing leisure boating activities and associated stresses [9,20]. With this in mind, there is a need to develop and implement conservation

* Corresponding author at: Bonefish & Tarpon Trust, 2937 SW Avenue, Suite 203, Miami, FL 33133, USA.
E-mail address: ross@bonefishtarpontrust.org (R.E. Boucek).

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actions that reduce this stress and increase the resilience of seagrass habitats [22,83].

Spatial management and marine zoning (i.e., access restrictions in specific areas), along with education, enforcement, and appropriate navigational aids can reduce impacts of leisure boating on seagrass ecosystems [7,61]. However, similar to other spatial management strategies, achieving conservation goals with marine zoning depends on social and organizational factors [24,31,70,79]. Co-production, broadly defined as "stakeholder engagement in collaborative knowledge production" [35] can be an asset to spatial management and zoning. For instance, stakeholder engagement within the Marine Protected Area (MPAs) planning process has been shown to improve local support for conservation goals, marine zoning design through increased information sharing, and post implementation monitoring capacity, all while reducing enforcement needs [37,43]. Despite the potential benefits of co-production in spatial management, there are few examples of this approach being applied to design marine zones aimed at protecting seagrasses from over-capacity leisure boating. This case study focuses on the collaboration between for-hire shallow water fishers, an important user group whose livelihoods are directly tied to the health and functioning of seagrass ecosystems, and scientists. Here, scientists and for-hire fishers co-designed research, co-produced science and co-disseminated the results to other stakeholders and managers to advocate for science-based spatial management of seagrasses (i.e., [35]). This approach is distinct from other examples, (e.g., [31] and [29]) that worked with both stakeholders and managers to coproduce spatial planning and could be considered a limitation of this work.

The Florida Keys (U.S.) is a tropical/subtropical archipelago located at the southeastern most corner of the United States. The island chain supports one of the largest seagrass meadows in the world, the only coral reef in the United States, and the third largest barrier reef tract in the world [33,45]. The resident population is supported by a blue economy where over 33,000 jobs are created by marine ecosystem, driving 58% of the local economy [56]. Along with diving, wildlife viewing, and other marine recreational activities, the Florida Keys supports a world-renowned shallow-water (<2 m water depth) recreational catch and release fishery for permit (*Trachinotus falcatus),* tarpon (*Megalops atlanticus)*, and bonefish (*Albula vulpes)*, better known as the flats fishery, which generates just under a half a billion dollars a year in economic impact. In comparison, snorkeling and diving at Florida Keys coral reefs generate $149 million per year [77,84]. Importantly, the species supporting this fishery are dependent on functioning shallow water seagrass ecosystems [1]. Over the last decade, tourism, and consequently leisure boating in the Florida Keys, has exponentially increased from 1.57 million visitors in 2008–5.5 million visitors annually in 2018 [53,56], both intensifying user conflicts and degrading seagrass habitats throughout the Florida Keys. In Monroe County (which encompasses all the Florida Keys), recreational fishing license sales are declining since 2014 [56]. In contrast, across the state of Florida, resident and non-resident participation in recreational fishing has increased from 1.6 million to over 1.8 million from 2016 to 2021 (ASA.org). These opposing trends of increased tourism within the Florida Keys and decreasing local participation in fishing likely indicate a decline in the proportion of experienced local fishers relative to visiting fishers that possess less local knowledge of the waters and ecological conditions of the Florida Key Keys.

In 2015, 24,281 ha of shallow water seagrass habitats were documented as damaged by propeller scarring, a 100% increase from 1995 in the Florida Keys [47]. In 2021, due to the COVID-19 pandemic, marine expenditures in the United States reached their second highest year in two decades, at $56.7 billion dollars, with Florida ranking highest among all US states [58]. This includes the biggest increase in first-time boat owners since the 2008 recession [76]. As a consequence of these novice, and often uneducated boat owners, the number of boater related accidents, injuries, and deaths in Florida have all increased by roughly 25% from 2019 [76]. The negative effects to seagrass meadows from this recent increase in leisure boating have not yet been quantified but are likely severe.

The marine waters of the Florida Keys fall within the Florida Keys National Marine Sanctuary (FKNMS). The FKNMS is part of the National Oceanic and Atmospheric Administration's (NOAA) National Marine Sanctuary Program [81]. Encompassing 9,515 km^2 in area, the FKNMS extends from the Florida peninsula to the south and west to the Dry Tortugas. The FKNMS is jointly managed by two state agencies (the Florida Department of Environmental Protection, and the Florida Fish and Wildlife Conservation Commission) and one federal agency (NOAA) under the advisement of a community-based Sanctuary Advisory Council (SAC; https://floridakeys.noaa.gov/). Through public and federal rule making processes, FKNMS aims to balance marine use with conservation of natural resources [72]. To achieve their mission, FKNMS limits marine activities that stress and/or damage environmentally-sensitive habitats that support fish and wildlife, separates conflicting uses, and prevents overuse by designating zoning that includes no entry, no motor, idle speed only, no anchor, and no fishing zones [72]. The FKNMS has historically adopted a top-down management approach that has been perceived negatively by resident stakeholders who generally oppose marine zoning plans in this region [81,86].

Following a decade-long planning process, in 2019, the FKNMS released a draft management plan to increase the resilience of Florida Keys' natural resources to ongoing and emerging stresses using marine zoning management tools known as the "Restoration Blueprint". In the decade leading to the Restoration Blueprint, for-hire fishers, scientists and other stakeholder groups (hereafter referred to as the flats fishing coalition or FFC) used co-production principles to advocate for marine zoning recommendations to reduce leisure boating stresses to seagrass habitats that support economically-important fisheries. This work overviews co-produced zoning recommendations, and compares the overall conservation benefits of the FFC zoning plan (i.e., area of seagrass and living bottom habitats protected) relative to the those of the Restoration Blueprint. To develop zoning recommendations, for-hire fishers and scientists used the co-production framework detailed in the Materials and Methods (Section 2.2).

2. Materials and Methods

2.1. FKNMS management plan

The FKNMS is divided into five regions ([72]; Fig. 1). The four eastern regions encompass urban and natural systems and fall on natural breaks in ecosystem structure, tourism usage, and resident demographics. The inshore waters of these four regions also make up the area for the shallow water flats fishery, supports recreational and commercial shellfish fisheries such as spiny lobster (*Panulirus argus*), stone crab (*Menippe mercanaria*), and blue crab (*Callinectes sapidus*), and harvest-oriented recreational fisheries of snappers (*Lutjanidae*), groupers (*Epinephelinae*), jacks (*Carangidae*), mackerels (*Scombrids*), penaeid shrimps, etc. The Upper Keys region, and the easternmost portions of the Middle Keys region are within the largest estuary in Florida (Florida Bay), with 80% of the estuary contained within Everglades National Park [66]. These areas are characterized by a patchwork of interconnected basins, shallow mud banks, seagrasses, mangrove islands, and tidal channels, which represent the historic center of the flats fishery [50]. The Middle Keys is characterized by enhanced tidal exchange between the Atlantic and Gulf of Mexico, and habitats consist of a mix of shallow mixed seagrass, hard bottom habitats, and seagrass covered banks that bracket major tidal flow ways [19]. The Lower Keys is made up of a chain of islands surrounded by extensive seagrass meadows, hardbottom, and reef areas. And, the Marquesas region is defined by two atoll formations, surrounded by seagrass meadows, enhanced tidal exchange, and apart from one building, anthropogenic development does not exist in this region (NOAA, 1996).

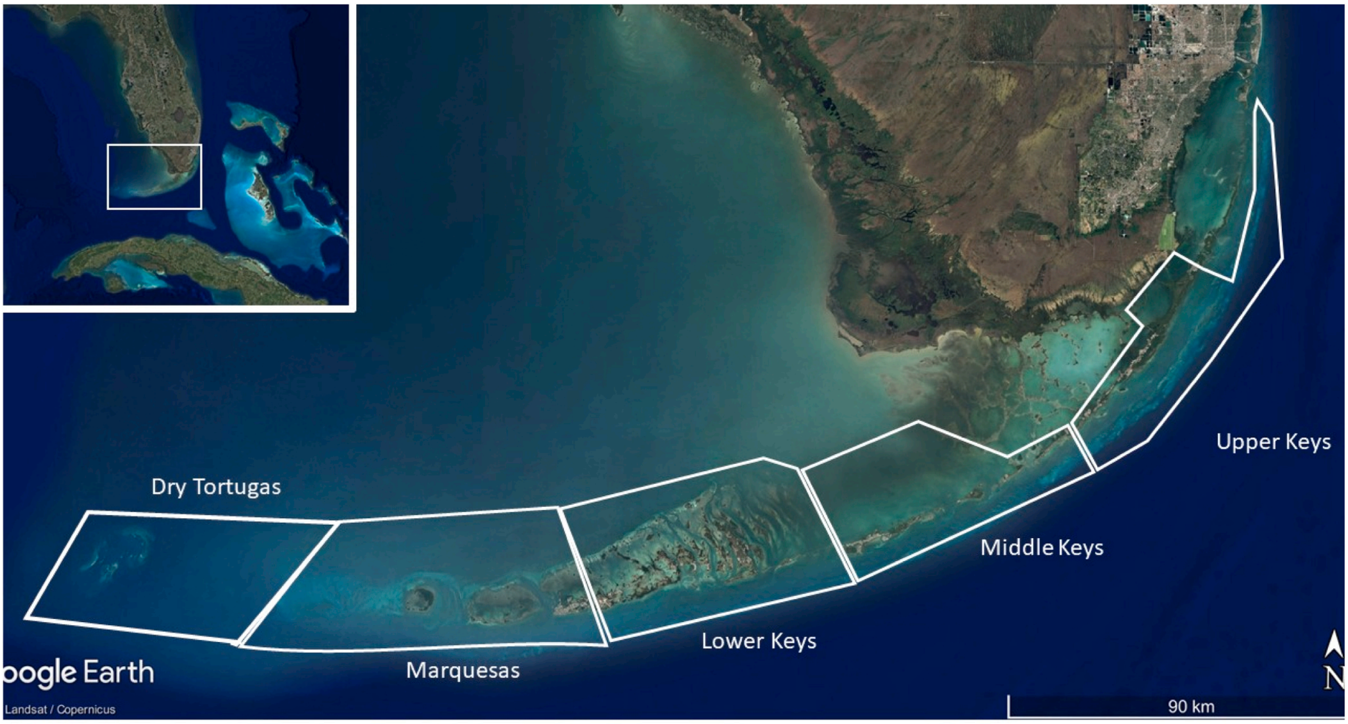

Fig. 1). Map of the Florida Keys National Marine Sanctuary and the 5 regions listed in the "Restoration Blueprint".

The 2019 *Restoration Blueprint* included multiple action plans with the intent to help counteract the decline of natural resources based on the 2011 FKNMS condition report (NOAA, 2011). Proposed changes included: expanding the boundary of the sanctuary, updating sanctuary-wide regulations, updating the individual marine zones and their associated regulations, and revising the sanctuary's terms of designation. Proposed boundary expansions would result in a 30% increase in FKNMS managed area. The proposed regulations also include 47 wildlife management areas, six conservation areas, two management areas, 17 sanctuary preservation areas, and nine restoration areas for a total of 78 marine zones (floridakeys.noaa.gov/blueprint/). Access regulations in these zones include: no entry, no motor, idle speed only, no anchor, the combination of no anchor and no motor, and no fishing.

2.2. Stakeholder Groups in FKNMS

FKNMS stakeholders groups have diverse interests and perspectives towards marine use and management within the FKNMS [64,80]. In designation of the first FKNMS management plan in 1997, Suman et al. [81] evaluated three stakeholder groups' perceptions towards the plan's interventions. Suman et al. [81] showed that commercial fishers felt highly alienated in the process of zone designation and displayed a sense of anger and powerlessness with respect to what they considered to be an attempt to exclude their group from fishery harvest refugia. Dive operators were the most engaged but were concerned that future zoning regulations would impact their livelihoods. Last, environmental groups were the strongest supporters of more restrictive regulations at the time. These three groups have been the focus of long-term studies gauging stakeholder perceptions and attitudes towards FKNMS [32,52,62]. In a recent survey gauging marine recreation participants, primary snorkelers and divers, perceptions of user crowding of FKNMS showed that users felt very satisfied and only slightly crowded while snorkeling and diving [4].

FKNMS acknowledges at least 11 other stakeholder groups that are represented in the FKNMS Advisory Council (SAC). The SAC serves as an avenue for members of the community to get involved with FKNMS. Volunteer members of the SAC come from each stakeholder sector, attend regular meetings and act as a liaison between the public and FKNMS. Stakeholder groups represented on the SAC include for-hire fishers and recreational fishers (i.e., fishing), the boating industry (i.e., tourism interests), Monroe County residents (citizen at large), research and monitoring, archelogy and underwater cultural resources representatives.

Two hundred and seventy-six shallow water for-hire fishers in FKNMS are represented by two regional fishing guide associations, the Florida Keys Fishing Guides Association (FKFGA, established in 1956), and the Lower Keys Guides Association (LKGA, established mid 2000s). Their collective missions are to ensure sustainable management of shallow water marine resources, while preserving the cultural importance of sportfishing to the Florida Keys. Membership age and experience in the fishery, whether or not they are born within the archipelago (i.e., conchs; Barnett and Barnet [6]), and fishing practices vary. These traits influence fishery practices, vessel types, and perceptions towards FKNMS and spatial management. For instance, Costa et al. [28] showed that shallow water FKNMS for-hire fishers operating within Everglades National Park have varying harvest preferences, with 50% of for-hire fishers preferring catch and release only regulations for all species within Everglades National Park, 41% preferring catch and release only regulations for some species, and 9% preferring status quo harvest regulations. Similarly, perceptions towards Everglades National Park management were divided, with 36% of respondents expressed satisfaction, 36% expressed dissatisfaction, and 29% being neither satisfied nor dissatisfied [28].

Many of the non-fishing leisure boaters that interact with seagrass meadows fall within the tourism sector. This includes non-residents that bring their private vessel to FKNMS or rent vessels to engage in various marine uses (fishing, snorkeling, anchoring and recreating in shallow waters, etc.). Non-residents and residents differ in their awareness of environmental management in FKNMS. For instance, Quenée [64]) found that 40% of visitors that participated in a FKNMS stakeholder perception survey had not heard of FKNMS. Environmental impacts of this sector have been documented in coral reef habitats. During a two-day event called lobster mini season, approximately 50,000 boaters, majority nonresident, attempt to catch lobsters. Following this event, Hartman [41] documented a 100% increase benthic habitat damage in fished areas compared to protected areas. Trends in the number of non-residents that bring their personal vessels to FKNMS vs. resident vessel use over time unfortunately are not quantified.

Other tourism-based leisure boaters include personal watercraft tour operations that transit across shallow seagrass meadows, shell collecting tours, sunset tours, and operators that take tourists to shallow water seagrass and sand areas for non-consumptive recreation. This user sector is presently growing. In response to this expansion, in 2022, the Florida Fish and Wildlife Conservation Commission issued a livery permit requirement for those that rent motorboats, PWCs, paddlecrafts, sailboats or houseboats in order to improve education, accountability and safety for owners and operators (FWC Livery). In 2023–2024, there were 71 registered livery operations in the FKNMS (FWC Livery). The environmental impact of this marine use is not quantified, but previous work has demonstrated that overcapacity eco-tourism can result in adverse environmental impacts [82].

Multiple regulatory agencies are recognized as stakeholders in FKNMS and serve as either voting or non-voting FKNMS SAC members. These include; local and county government, four municipalities, and five federal entities, the National Park Service, the US Fish and Wildlife Service, the Environmental Protection Agency, the U.S. Coast Guard, and the U.S. Navy. Agencies with different missions and philosophies towards management have created complex power dynamics that have slowed the completion of the Restoration Blueprint [60].

2.3. The Co-production conceptual model for shallow water marine zoning

The FFC is led by three non-governmental organizations (NGOs): the Lower Keys Guides Association (LKGA), the Florida Keys Fishing Guides Association (FKFGA), and Bonefish and Tarpon Trust (BTT). BTT is a science-based habitat-dependent outdoor recreation and conservation organization, or boundary organization [10,65] that funds and conducts research to identify and resolve fisheries and habitat stresses affecting the seagrass-dependent fisheries of bonefish, permit, and tarpon in the

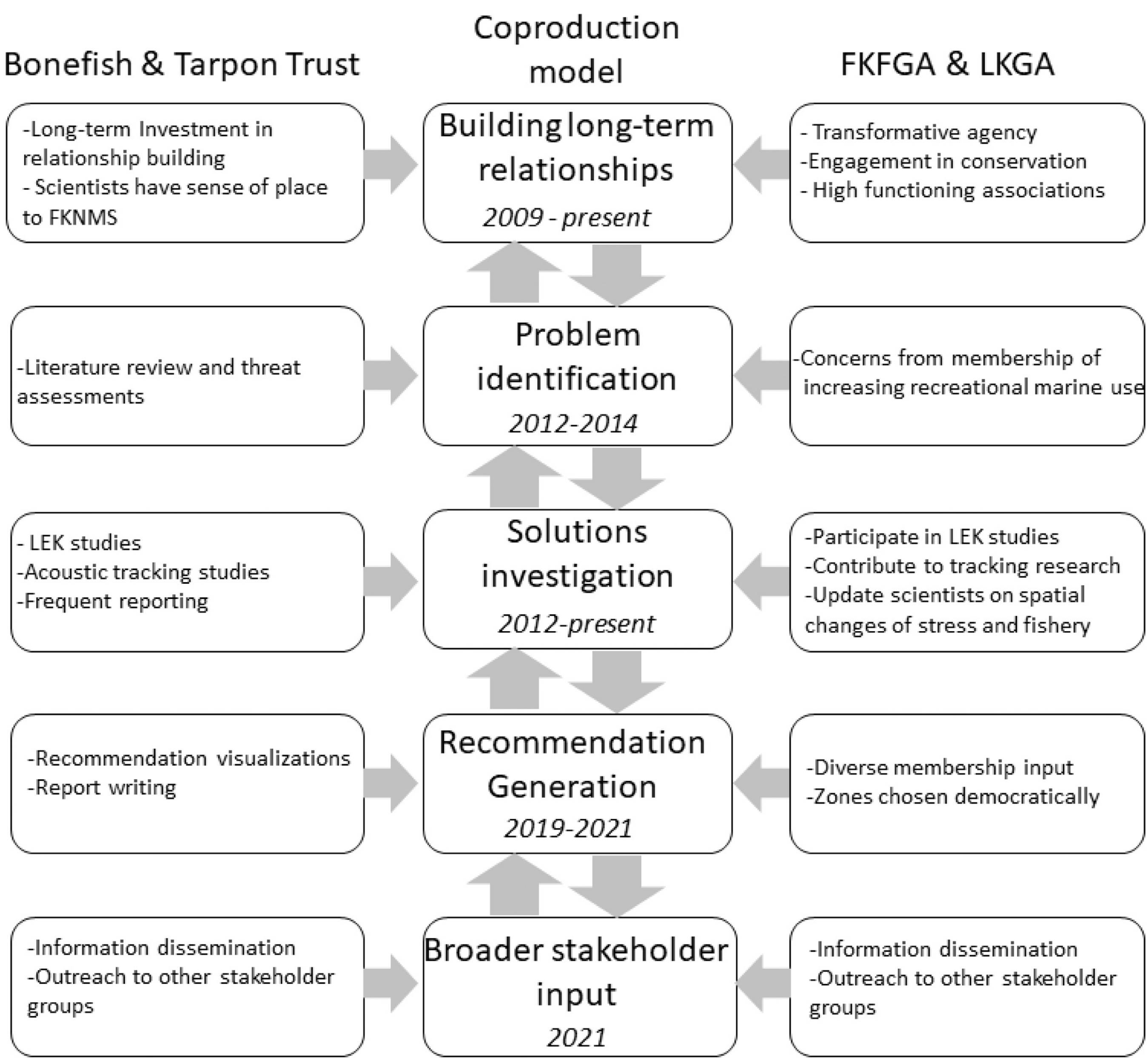

Fig. 2). Co-production model used to generate shallow water zoning recommendations. Center boxes identify target benchmarks for the co-production process, and their chronology (italics). Left and right boxes show tasks preformed by BTT (left) or FKFGA and LKGA (right) during the co-production process.

Southeast U.S. and Caribbean. Since 2008, all three organizations have served as stakeholders in FKNMS management processes, either as members of working groups or of the FKNMS SAC [5,11].

The co-production framework used here is presented in the conceptual model in Fig. 2, an approach that follows the three phases of co-production defined by Bremer et al. [16]. These include: 1) the co-design of research, 2) the co-production of science, and 3) the co-dissemination of the results [16,35]. Our approach to engagement is collegial, where stakeholders and researchers work together, and decisions are made by consensus of the team [35]. Six benchmarks were achieved in an iterative process that began with an investment among all groups to build long lasting relationships between for-hire fishers (FKFGA and LKGA) and scientists (BTT; e.g. [67,85]). These relationships allowed for a sustained two-way flow of information and joint learning, both key to co-production. Through the relationship building phase, groups co-advocated for increased harvest regulations for the permit fishery experiencing a localized decline [13], and co-designed sustainable fishing access opportunities in partnership with Everglades National Park managers during revisions to their general management plan in 2016 (BTT recommendations; 2013).

From 2012–2014, maintaining goal-oriented focus to identify problems stressing fisheries was prioritized (step 2 in the co-production model, Fig. 2). These included spawning aggregation overfishing [42], declining water quality, catch and release best practices improvements, and increasing leisure boating. Specific to leisure boating, for-hire fishers expressed concerns of fishery changes occurring in areas where boating activity was increasing, frustration with the lack of appropriate governance to manage leisure boating growth, and worry about the negative impacts to the quality of the natural experience they can provide clients when leisure boaters encroach and impact fishing areas. Collectively, the three members of the FFC agreed that marine zoning, increased signage, and increased enforcement capacity will reduce this stress, and that FKNMS management revisions process (2011–2022) may provide a political window of opportunity for increased marine zoning.

Once problems were identified, several studies were co-produced (step 3 in co-production model, Fig. 2). These include mapping spatial and temporal patterns in shallow water fishing effort to identify important areas for protection (year 2012–2015; [5,11,71]). It also included funding a seagrass propeller scarring survey in FKNMS (year 2015; [48]), and acoustic telemetry studies of permit, tarpon, bonefish and crevalle jack (*Caranx hippos*) to identify high use shallow water habitats and spawning sites (years; 2016 to present; [17,36,39,51]). Here, for-hire fishers helped identify key locations for acoustic receivers and donated time for tagging. Dissemination of results occurred through the research process at presentations during fishing tournaments, at for-hire fisher association meetings, and over frequent phone conversations and one on one meetings with scientists.

After the release of the Restoration Blueprint, from 2019 through 2022, a committee from each FFC members made up of 7 for-hire fishers and two scientists convened, and drafted zoning proposals (Step 4 in co-production model, Fig. 2). For-hire fisher zone rationale generally followed three themes: 1) reducing unintentional vessel groundings and propeller scarring, 2) minimizing the spread of leisure boating into sensitive shallow waters that negatively affect habitats and fish behavior, and 3) reducing acoustic stress from vessels traveling at high speeds over fish resting areas and migratory routes.

Scientists at BTT compiled relevant literature related to shallow water fisheries in the FKNMS. Several metrics were used to evaluate priority areas: 1) spatial patterns in fishing effort as a proxy for important fish habitats [11,49], 2) areas that were more resistant to long-term patterns of decline in bonefish, which may indicate preferred habitats for target species ([46,66]; e.g. [8]), 3) degree of propeller scarring [48], and 4) areas where completed or ongoing acoustic tracking studies of bonefish, permit, and tarpon, suggest high use for multiple species ([17, 39]; Larkin et al., in 2023). These metrics were qualitatively scored on a 1–5 scale.

Zone visualizations and summary reports were distributed among all FCC members (Supplement 1 and 2, Step 5 of co-production model, Fig. 2). Fisher association members democratically decided zone location, regulation, and geometry through a voting process that followed a presentation of proposed regulations at their association meetings by BTT. Membership acknowledged that these regulations would affect their fishing practices by increasing time to reach fishing locations. These zones also potentially create more hazardous travel conditions during windy days since members would be unable to travel over shallow protected waters to avoid high sea-states in open waters. Several adjustments to draft zoning plans were made based on full membership input. These include allowing on-plane access through channels within zones 47 (Marquesas), 43 (South Lakes) and 1 (Ocean Reef). Revisions to the southeastern quadrant of zone 33 were made to increase accessibility to a sandbar used for weekend gatherings by Florida Keys residents and for-hire fishers. Access adjustments were made to zone 13 (Bird Key Islamorada), that initially was proposed to be a no-entry zone to protect nesting birds, but since a contingent of FKFGA use that area to catch bait daily, draft recommendations were revised to include this zone as a no motor zone.

Last, broader stakeholder perspectives were included in the recommendations. FFC representatives met with over 12 NGOs with diverse missions (e.g., Audubon Society, National Parks Conservation Association, Marine Conservation Institute, The Nature Conservancy, American Sportfishing Association, and others), as well as other local influential fishers in the community that do not target shallow water flats fishes but use the habitats as places to catch bait (Far Out Fishing Charters, Spindrift Fishing Charters, Islamorada Charter Boat Association, and others) and would be affected by proposed access restrictions. Zoning recommendations were revised again to incorporate this external input. Notable revisions in this process included adjusting 10 zones that FFC requested to be modified from no-entry to no-motor zones in the Lower Keys region, to a zoning scheme where a 13 m no-entry zone surrounding islands are embedded into no-motor zones (Supplement 2). This compromise satisfied NGO concerns that vessel traffic even without the use of a combustion engine would disrupt roosting and nesting birds, and that a small no-entry halo would reduce stress to birds, while allowing access to fishing in the larger seagrass meadows surrounding these islands. A second revision from this process was adjusting the geometry and regulations within zones 43 and 47. These zones are used daily by offshore fishers to catch bait. Offshore fishers agreed that regulating vessel speed within these shallow water areas would benefit the seagrass meadows. However, expressed concerns that regulated as a no-motor would prohibit them from catching bait. All of these recommendations were submitted to the FKNMS in the fall of 2021 by the 3 members of the FFC during their public comment period.

2.4. Calculating conservation benefits through habitat protection

Geographic Information System (GIS) - based methods using ArcGIS Pro 2.8.0 (ESRI) were used to map FFC recommended zones and compare them with FKNMS proposed zones in the Restoration Blueprint. FFC zoning recommendations were digitized and traced with ERSI edit and sketch tools. To contrast conservation benefits between FKNMS' Restoration Blueprint and the FFC recommendations, the total area of seagrass and living bottom habitats protected by FFC and FKNMS recommendations were quantified. Both habitat types are foundational to the shallow water fish communities that make up inshore and offshore recreational fisheries (e.g., [34]), provide important ecosystem services via erosion and storm damage protection (e.g., [30]), carbon sequestration (e.g., [3]), and are essential habitats for charismatic and endangered megafauna (e.g., [75]). Hectares of seagrass and hardbottom protected in the FKNMS proposal with FFC recommendations for the total area protected and within each management region were compared using chi-squared tests.

3. Results

3.1. FFC marine zone summary

Overall, FFC provided comments on 42 of the 47 FKNMS management zoning proposals (Fig. 3). Of those zones, 17 zones were originally proposed by FKNMS in the Restoration Blueprint and supported by FFC as proposed. FFC requested modifications to 25 FKNMS proposed marine zones and recommended an additional six protected areas to be added to the management plan.

Of the 25 modifications proposed by FFC, 18 recommendations were greater than 100 ha (Table 1) and were intended to protect seagrass meadows that support the shallow flats fishery from increasing leisure boating activity. The remaining zones were generally smaller FKNMS proposed no entry zones to protect wading bird rookeries (< 1 km). FKNMS proposed regulations within these wildlife protection zones are generally no-entry zones that extend 100 m from the shoreline. FFC worked with avian conservation groups and other stakeholders to agree to modify the regulations of these zones, not their overall size, but to smaller no entry zones (extending 13 m from shore) embedded within larger no motor zones (extending 100 m from shore; FFC official position, Supplement 3). These proposed changes would allow fishing access to shallow water habitats within the no-motor halo without disturbing nesting and roosting seabirds.

Across the proposed zones greater than 100 ha, there are areas with high fishing effort, high resistance to bonefish declines, and high degrees of propeller scarring (zones 10, 11, 12 and 14; Fig. 3; Table 1), areas with high fishing effort and low levels of propeller scarring (zone 26), and also remote areas where fishing effort and propeller scarring are both relatively low (zones 47 and 48). Acoustic tracking research provided insights on the potential benefits afforded by several marine zones that are high use areas for Bonefish, Permit, and Tarpon (zones 3, 14, 26, 33, 43 and 47). Acoustic telemetry also showed that a subset of zones would create an MPA network benefiting permit (Fig. 4). In the Marquesas region, proposed zones 43, 47 and 48 would protect large contiguous areas that are of high use for permit and are connected via adult migration to a recently implemented spawning aggregation MPA, in order to reduce aggregation overfishing for permit (Brownscombe et al., 2022; Fig. 4).

Considering fisher perspectives, over half of these zones (10 of 18; Table 1) were perceived as important fishing areas for all three focal species, six zones support two of the three focal species, and one zone only supports a permit fishery. For-hire fishers also recommended the expansion of several FKNMS proposed zones to include deeper water habitats (2–3 m) used by tarpon that are perceived to be affected by leisure boats traveling at high speeds (zones 6 and 8). Collectively, for-hire fishers decided that no motor zones and idle speed zones should function as a deterrent to entry or high-speed transit, while still allowing quieter and less physically damaging access to those areas.

3.2. Calculating conservation benefits through habitat protection

Overall, FFC recommended a total of 13,195 ha of seagrass, and 3,257 ha of hardbottom habitats be zoned for protection. FFC recommended seagrass protection more than double that of what FKNMS recommends, and recommended the protection of 60% more hardbottom habitat relative to FKNMS (Fig. 5). The majority of FFC recommended additional seagrass protections were within the Upper Keys region, Middle Keys region and in the Marquesas management region, where FFC zoning recommendations protect approximately 70%, 50%, and 260% more seagrass area relative to the FKNMS proposal, respectively ($X^2 > 6$, $p < 0.05$). In contrast, in the Lower Keys region, seagrass protections were not significantly different between the FFC recommendations and the FKNMS recommendations ($X^2 = 1.96$, $p = 0.16$). Within the Upper Keys region, Lower Keys region, and Marquesas region, FFC recommendations protected 120%, 64%, and 62% more hardbottom areas than the FKNMS proposal ($X^2 = 7.5$, $p < 0.01$). Hardbottom protection between FFC and FKNMS recommendations were not significantly different for the Middle Keys management region ($X^2 = 3.4$, $p = 0.06$).

Total area comparisons between the FKNMS Blueprint proposal and the FFC recommendations by zoning type (i.e., no entry, no motor, idle speed, no anchor, and the combination of no anchor and no motor) showed similar trends (Fig. 6). FFC recommendations zoned 138%, 79%, and 130% more seagrass to be protected with idle speed, no-motor, and the combined zoning type of no motor and no anchor relative to the FKNMS proposal (, $X^2 > 22.1$, $p<0.001$). In contrast, FKNMS proposal zoned 233% more area as no-entry ($p<0.001$, $X^2 = 37.7$). No anchor zoning proposals were not different between groups ($X^2 = 0$, $p > .99$). For hardbottom protection, FFC recommendations zoned 167% and 184% more area as no motor, and no motor and no anchor relative to the FKNMS Blueprint ($X^2 > 28$, $p < 0.001$). The FKNMS hardbottom proposal zoned 7 times more area as no entry relative to FFC recommendations. Last, no anchor and idle speeding hardbottom zoning area were no different between FFC and FKNMS recommendation ($X^2 < 2.37$, $p > .123$).

4. Discussion

In this effort, scientists and stakeholders co-produced recommendations to increase protections for shallow water habitats that exceed regulations proposed by the regulatory authority in the region, the FKNMS. Centered on key areas of productivity for the shallow water flats fishery, the recommendations of the FFC propose to zone twice as much seagrass and 60% more hardbottom habitat for vessel speed or propulsion type restrictions. In addition, these stakeholder co-produced recommendations would create at least one marine zoning network that would protect large contiguous foraging areas, along with spawning sites for permit in the Marquesas management region. In the context of spatial management, fishers requesting access restrictions at this scale is uncommon [65], although others, such as the Hawke Box on the Labrador continental shelf is a key example [44].

The foundation for co-production was achieved through two key processes. First, the research group (Bonefish and Tarpon Trust) invested in long-term community engagement that allowed co-production to evolve over a decade. Similarly, scientists had a strong connection to the region which helped trust-building among partners (e.g., [23]). Second, for-hire fishers involved here would be best classified by Shephard et al. [74] as those that are the "most developed stewards", with a connection, identity, care and knowledge of the environment, and transformative agency [2]. In the FKNMS shallow water for-hire industry, experiential learning and stewardship of aquatic environments for new entrants is developed through informal mentorships that instill an ethos of catch and release, an appreciation of the fragility of shallow water habitats, and the nuances of fishing areas to reduce for-hire fisher conflicts [2]. These traditions have been in place since post World War II and have led to successional social development of for-hire fishers that are not only stewards, but advocates for environmental change, and have a large influence on regional environmental policy (e.g., Captainsforcleanwater.org).

Shallow water for-hire fishers spend an average of 164 days per year fishing on seagrass meadows and have on average 19 years of experience fishing the region [28]. As such, the collective membership of 276 for-hire fishers spends a total 45,264 days per year using ecosystem services provided by seagrass meadows. Through this process, other stakeholders that use these areas were also engaged, including offshore recreational fishers, environmental NGOs and for-hire Personal Watercraft (PWC) tour operators. Through engagement with environmental NGOs and offshore recreational fishers, revisions to seagrass protection recommendations were made to address their concerns. There were challenges to engaging PWC tour operators, largely because of frequent operator staff and leadership turnover. In this, FFC leadership would

Fig. 3). Visualizations for the FKNMS proposed zones (panel A, C, E & G), and FFC proposed zones (B, D, F, H) for the four focal regions. Black hashed polygons represent idle speed zones, pink polygons represent no anchor zones, orange polygons identify no motor zones, black hashed and orange outlined polygons show no motor and no anchor zones, and red polygons represent no entry zones. John Pennekamp State Park, and Lignumvitae State Park's existing no motor zones and the Western Dry Rocks no fishing MPA are shown with green shaded polygons.

Table 1)
Summaries of FFC zone recommendations that exceed 100 ha. Table includes scoring on the degree of propeller scarring [48], fishing effort intensity [11], quality of bonefishing within each zone during a long-term population decline spanning from 1996 to 2015 [49,71], and an evaluation of the number of individuals, and number of different species detected within these zones from acoustic telemetry studies (Brownscombe et al. 2022; [14,39]). The fisheries that are supported in these zones (T= tarpon, B = bonefish, P= permit), and fisher justification for each recommended zone.

Recommendation		Science support				Fisher justification	
Zone #	FFC	Propeller scarring	Fishing effort	Resistance to bonefish decline	Tracking support	Fishery supported	Zone rationale
1	New zone	1	2	3	2	T,B,P	Concerns of future increases in marine use
3	Support	2	3	3	4	T,B,P	Increasing marine use
6	Modify	4	4	3	3	T,P	Zone boundary does not protect migrating tarpon, dense boater gatherings
8	Modify	3	4	3	3	T,P	Zone boundary does not protect migrating tarpon, dense boater gatherings
9	New zone	NA	5	3	NA	T,B	High speed boats displacing tarpon
10	Modify	5	5	4	NA	T,B,P	Vessel groundings, high speed transit through fish resting areas, increasing PWC use
11	Modify	4	5	4	NA	T,B,P	Vessel groundings, high speed transit through fish resting areas, increasing PWC use
12	New zone	4	4.5	5	NA	T,B,P	Vessel groundings, acoustic stress to fish
14	New zone	4	4	5	5	T,B,P	Vessel groundings, high speed transit through fish resting areas, increasing PWC use
16	New zone	5	2	1	NA	T,B	Increasing marine use
17	Support	4	NA	NA	NA	T,P	Increasing vessel groundings
18	Support	5	2	NA	NA	T,P,B	Vessel groundings, PWC use, dense boater gatherings
19	Support	5	3	NA	NA	T,P	Increasing vessel groundings
26	Modify	1	5	1	5	T,P,B	Vessel groundings, dense boater gatherings
33	Modify	1	4	1	4	T,P,B	Vessel groundings, dense boater gatherings, high speed transit through fish resting areas
43	Modify	2	3	NA	5	T,P,B	Vessel groundings, dense boater gatherings, high speed transit through fish resting areas
47	New zone	1	2	NA	4	T,P,B	Increasing flats fishing effort, concerns of future increases in marine use
48	Support	0	NA	NA	3	P	Protect nearshore permit aggregations

engage, educate, and develop informal agreements with operators to conduct tours in places that would minimize user conflict (Keywest Anglers User Conflict Relief Request). However, as operators exited the business, maintaining engagement and operator involvement proved to be a difficult barrier. One stakeholder group that was not included in this process was non-resident leisure boaters that either rent vessels or bring their own personal vessel to the FKNMS for recreation. This group is made up of hundreds s of thousands of disconnected individuals with differing conservation values from across the entire southeastern United States. This stakeholder group does not have organizational representation, and FFC could not identify a clear pathway for incorporating their perspectives into zoning scheme.

Co-production is an iterative context-dependent process, as such there is no single framework that matches perfectly to all conservation issues [26]. Though execution of co-production may vary based on context, several consistent principles exist in successful co-production where efforts are context-based, pluralistic, goal-orientated, and interactive [68]. Di Franco et al. [31] used a governance intervention approach to develop management interventions for 11 Marine Protected Areas (MPAs) in the Mediterranean Sea. This process included the establishment of local governance groups, structured surveys to query managers and small-scale fishers on management interventions, and meetings to discuss effectiveness and feasibility tools. Through this process, small-scale fishers had mostly positive perceptions towards MPA co-produced management interventions. Here, each MPA regulation was decided accounting for local contexts, allowing for power sharing among managers and small-scale fishers, with a focus on improving fish productivity, and engagement occurring across the entire planning process.

FFC followed a less formal stakeholder engagement approach. This approach did not include stakeholder surveys or regularly occurring and structured workshops as used by Di Franco et al. [31]. Given the historical perception of top-down spatial management in FKNMS [81], the use of a formal and structured interactive framework could have created a perception of hierarchical power with stakeholders feeling as test subjects instead of partners, detracting from the goal-oriented focus of reducing leisure boating stress. Other case studies have shown that workshops may not be the most effective medium for co-production. For instance, Caro et al. [21] found that iterative discourse to be far more effective than formal all-inclusive stakeholder workshops in the island of Pemba in the Zanzibar archipelago, Tanzania. These place-based contexts emphasize that no single framework for co-production will match all social-ecological problems (i.e., [26]).

Minimizing stakeholder fatigue was also prioritized, leadership teams within the FFC avoided setting formal and regular meetings specific for this effort that may be perceived as an obligation, rather than an organic process to improve the status of FKNMS. Instead, opportunities for co-production and benchmark accomplishment were maximized during existing in-person gatherings at fishing tournaments, LKGA and FKFGA Board of Director meetings, annual membership meetings, and other similar community events, with much of the technical effort and steering occurring in smaller gatherings with more engaged group members. Being less sensitive to stakeholder fatigue has been noted as an important stress on co-production. Roux et al. [68] was less successful in achieving co-production benchmarks in Garden Route National Park in South Africa. Authors attributed several of their shortcomings to institutional top-down bounds to Park vision and planning, the lack of consideration for the complexity of the social-ecological system, lack of urgency for responsive adaptive management where “the time and effort for a mid-term review is just not worth it”, and stakeholder fatigue. In their model, South Africa National Parks staff and stakeholders attended over 20 meetings in the planning process, as a consequence, internal and

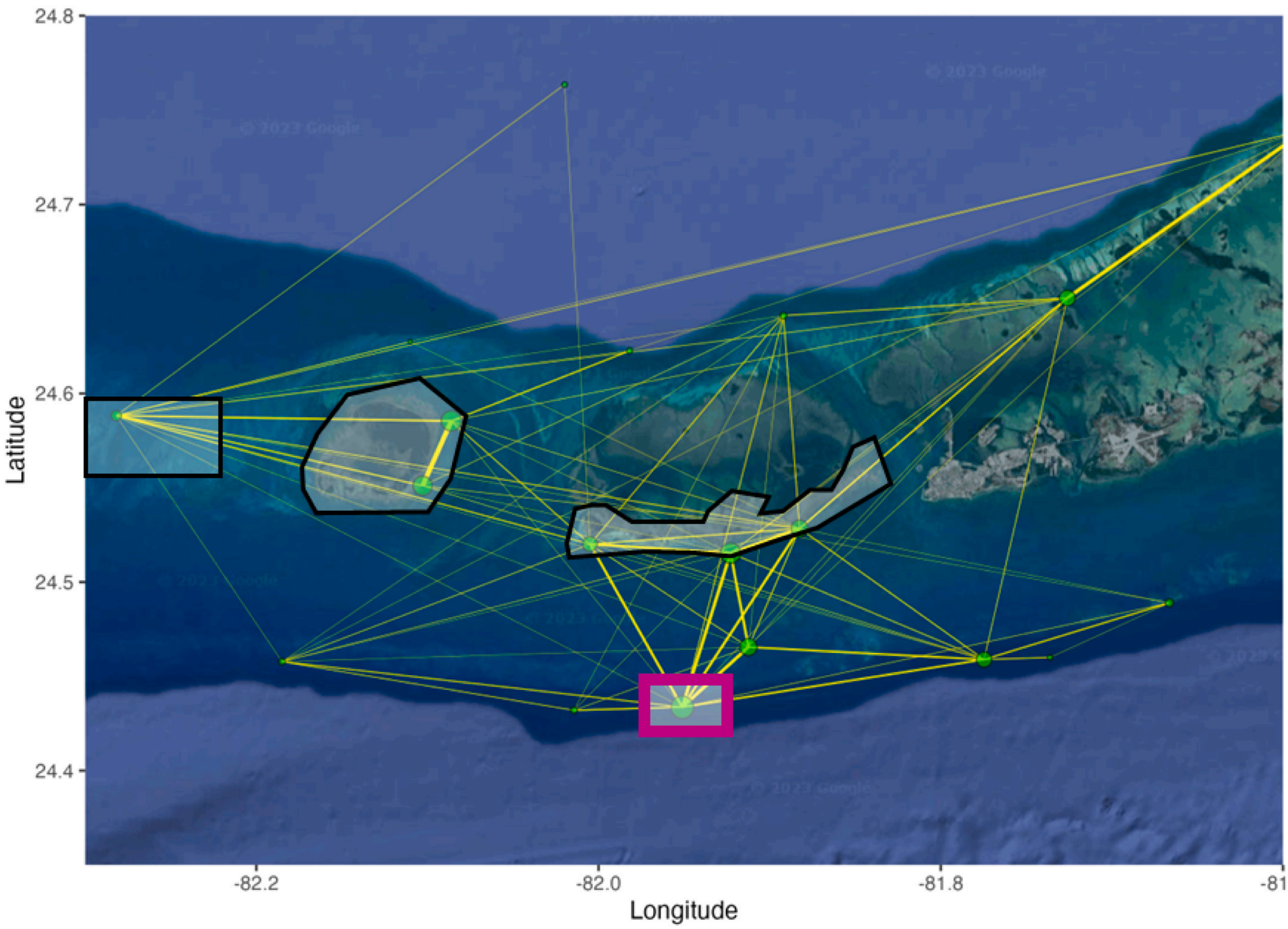

Fig. 4). Movement networks for permit in the FKNMS Marquesas region from 2015 to 20219 described by Brownscombe et al. (2022). The size of the node size represents its degree (number of unique connections to other nodes) and edge (yellow line) width represents its weight (number of movements between connecting nodes). Black outlined polygons approximate FFC recommended idle speed zones, and the pink box identifies the Western Dry Rocks seasonal no fishing MPA aimed at protecting permit and mutton snapper spawning aggregations.

stakeholder fatigue caused a decline in the quality of engagement.

In FKNMS, there are numerous conservation non-governmental organizations (NGOs), academic groups, and government institutions that request time from FKNMS marine stakeholder groups. A google scholar search using "citizen science" "FKNMS" "stakeholder" and "survey" identified 21 different dissertations, peer reviewed articles, and government reports that engaged FKNMS stakeholders in their research since 2019 (Supplement 4). In that same period (2019–2023), at least 14 other NGOs requested LKGA and FKFGA support for their respective environmental causes either through advocacy, restorative actions (mangrove planting, beach cleans, coral outplanting, etc.), or leveraging their expertise of seagrass ecosystems. Even the focal management institution, the FKNMS, obligates their stakeholder volunteer advisory council to attend six, eight-hour meetings each year and several FKFGA and LKGA members have served terms on this Sanctuary Advisory Council.

Given this context, the opportunistic co-production model taken here was effective in achieving our objectives. Nel et al. [59], similarly was very judicious with stakeholder time by providing a range of participation opportunities for engagement, completing technical work behind the scenes, and allowing time for participation through workshops. Molino et al. [55] implemented a stakeholder needs study using a document analysis approach that mapped research priorities expressed in non-journal publications by stakeholder communities in the Northeast U.S., to catalyze engagement and reduce stakeholder fatigue at early stages of the process. As co-production, science engagement, and citizen science all become more widely applied, emphasis should be placed on designing best practices to maximizing stakeholder participation and input yet minimizing stakeholder fatigue.

To effectively reduce leisure boating impacts to seagrass ecosystems necessitates a comprehensive approach that includes designations of regulatory zones, appropriate enforcement capacity, educational investment, and the implementation of navigational aids ([7]; Careño and Lloret, 2021). An indirect value of co-producing zoning regulations with the FFC is that there may be a degree of self-regulation that reduces enforcement needs (e.g., [63]). This is especially the case in the proposed idle speed zone in the remote area of the Marquesas islands (zone 47), where shallow water for-hire fishers are more or less the exclusive marine resource user, and law enforcement presence is minimal. In terms of navigational aids, advancements in GPS technology, and their widespread use among recreational fishing vessels [27], provides a cost-effective way to improve recognition of these zones [25]. Commercial and recreational fishers and scientists can work with GPS companies to increase visibility of regulated zones on electronic charts, and potentially develop materials to educate marine resource users on how to interpret zoning on those charts. Such initiatives are already underway in several countries such as the UK, with the #ProtectOurBeds campaign and the mobile app Savvy Navvy, and in Spain, with the mobile app PosidoniaMaps, which provides direct access to high-resolution underwater seagrass maps to ensure proper mooring and

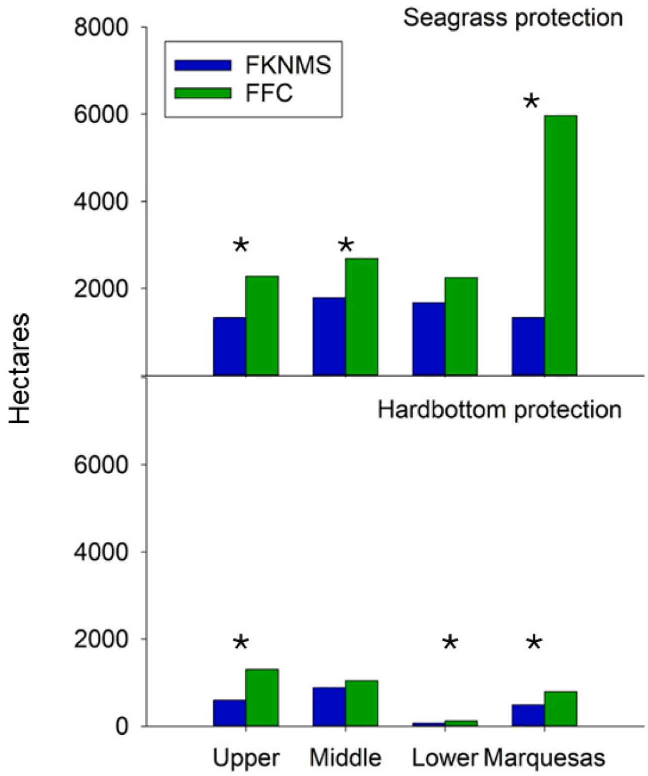

Fig. 5). Hectares of seagrass (upper panel) and hardbottom (lower panel) zoned for protection in the FKNMS proposal (blue bars) and FFC proposal (green bars) by region. Stars identify significant differences between the two proposals.

anchoring. Increasing on-water navigational aids can also be achieved through public private fundraising partnerships to help fund deployment and maintenance costs of this infrastructure.

The primary zoning methods recommended were no motor and idle speed only zones, both of which allow for access but with limitations on boat speed or propulsion type. Though restricted access is allowed, eliminating all access to marine zones has shown not to offer a greater conservation benefit. For instance, previous research by Greening [38], showed there were no significant differences between propeller scarring in “exclusion zones” (i.e., no entry), and “caution zones” (i.e., access allowed with penalties if benthos is damaged) in Tampa Bay, FL, USA. Indeed, idle speed only and motor zone regulations have been applied in the past with success if appropriate education and signage are in place, and stakeholders are compliant [38,7]. For example, [47] provided evidence that marked marine zones resulted in noticeable reductions in propeller scarring following the implementation of these spatial regulations in FKNMS. The FFC proposed zoning regulations are majority idle speed only followed by no-motor zones. Though no-motor zones are more restrictive, and likely have more benefits to fish and wildlife, the degree of ecological improvement between no-motor and idle speed zoning are unknown. Future work comparing the efficacy of these zoning restrictions, relative to the social-economic consequences from loss of access will better inform spatial planning for seagrass protections both within FKNMS and elsewhere.

Limited research suggests that marine zoning or MPA benefits are optimized if the area of the protected matches, or is larger than, the home range of target species [12]. This can be achieved through a single large contiguous protected area, or networks of protected areas that are made up of smaller interconnected MPAs that protect target species, including their home ranges and movement corridors [54]. Using bonefish as an example, previous work has shown that individual bonefish utilized the entire 2,230 ha of coastline in Eleuthera, The

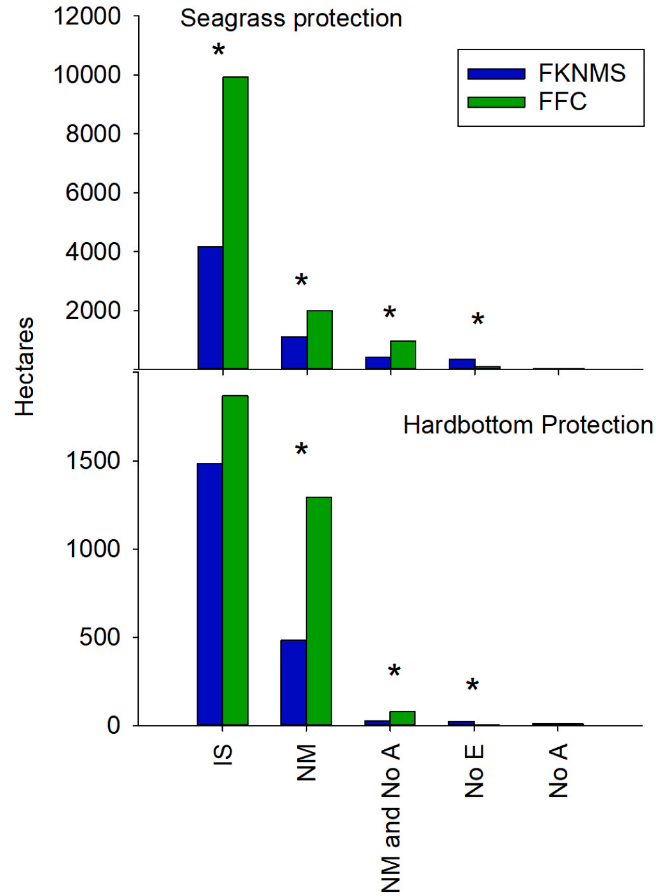

Fig. 6). Hectares of seagrass (upper panel) and hardbottom (lower panel) zoned for protection in the FKNMS proposal (blue bars) and FFC proposal (green bars) by zoning regulation. IS represents idle speed, NM represents no motor, No A represents no anchor, and No E represents no entry. Stars identify significant differences between the two proposals.

Bahamas [57]. A Mark-Recapture study showed that the average distance between mark and recapture for bonefish was approximately 3–11 km [15]. If we consider 3–11 km as a diameter of a circle, the area of those circles, which would be a proxy for their home range, is 324 – 1, 619 ha. In these FFC proposed recommendations, two proposed zones in the Marquesas management region satisfy this requirement to protect large contiguous areas of this size, zone 43 (approximately 3,000 ha) and proposed zone 47 (approximately 2,500 ha). These zones are of adequate size and represent core areas of the historic permit fishing areas in the Marquesas region. They also support a growing bonefish fishery ([14], unpub. data). Previously completed acoustic tracking research for permit show that zones 43 and 47 are high use areas for tagged permit (Brownscombe et al., 2022), and these zones are connected via permit and bonefish spawning migrations to the recently implemented Western Dry Rocks seasonal no fishing closure aimed at protecting a multi-species spawning aggregation site (Fig. 4; Brownscombe et al., 2022). If these zones are implemented, they will serve as important areas of research to evaluate fishery changes following these new regulations. Further, this potential MPA network would cause reductions in the local stresses from recreational marine use, and negative impacts from aggregation overfishing for permit, increasing the resilience of these fisheries.

5. Conclusions

This case study shows how a decade long collaborative effort between researchers and stakeholders led to management proposals that increased protections for seagrass meadows and their associated fisheries. Moreover, it presents a unique case study where fishers (commercial or recreational) specifically advocated for increased protection from local threats (i.e., leisure boating) they perceived as damaging to both seagrass habitats and fisheries resources at the expense of limiting their own access to seagrass meadows that they rely on. As leisure boating continues to increase in popularity, rapid assessments and efficient adaptive management implementation frameworks to keep pace with these stressors must be developed. FKNMS management plan revisions took over a decade to plan, and in 2024, are still in the revisions process. During that time, annual tourism visitation more than doubled, increasing existing marine use stresses, and creating novel stresses that were not considered in the early phases of this management process. Using co-production frameworks to identify and protect ecologically important areas is one tool that may help inform rapid and more comprehensive implementation of adaptive management.

Data Availability

Data will be made available on request.

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CRediT authorship contribution statement

Ross E. Boucek: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Kristin A. Anderson:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation. **Benjamin L. Jones:** Writing – review & editing. **Jennifer S. Rehage**: Writing – review & editing.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2024.106227.

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