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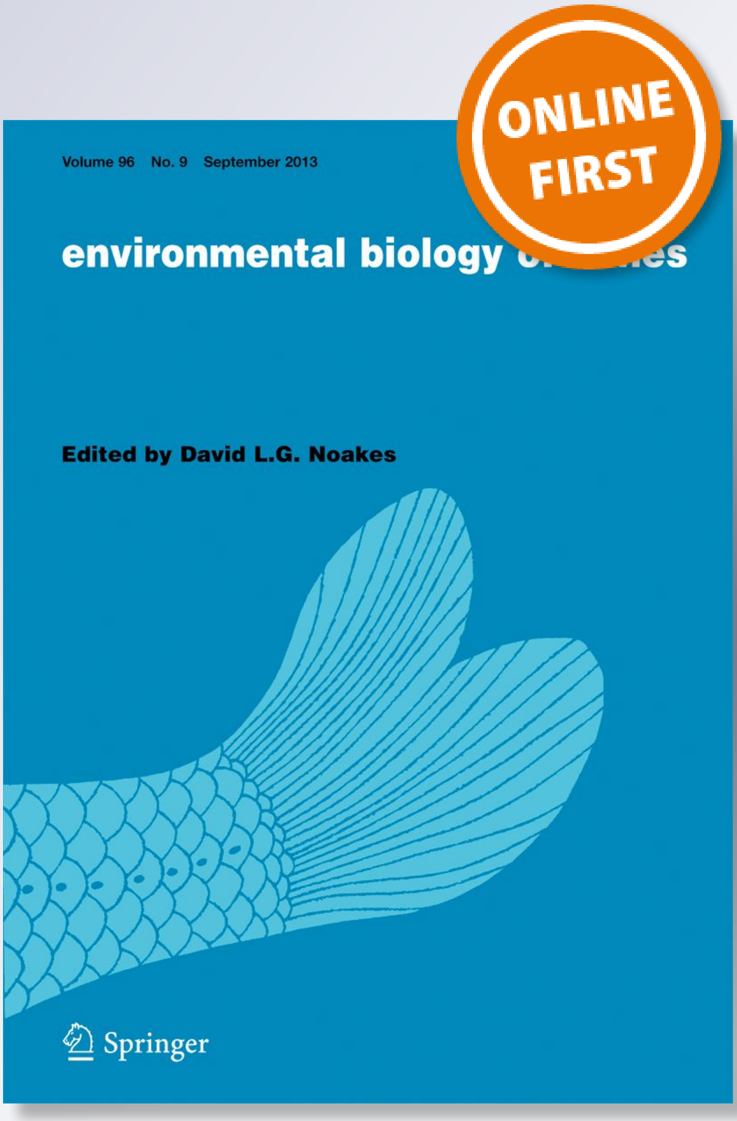

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Atlantic tarpon (*Megalops atlanticus*) nursery habitats: evaluation of habitat quality and broad-scale habitat identification

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Abstract Coastal habitats are threatened worldwide by habitat loss and degradation. These habitats play a crucial role as fish nurseries. Unfortunately, it is difficult to determine the impact of habitat degradation for many species because data are lacking on early life history metrics including growth (0.07 ± 0.04 SE mm/day in this study), survival (apparent annual survival 0.007 (95% CI: 0.001–0.033 in this study), emigration (27% in this study) and the spatial extent and condition of these habitats. The juvenile life stage of Atlantic tarpon (*Megalops atlanticus*), an economically important species in the Caribbean, sub-tropical and tropical Atlantic, and Gulf of Mexico, depends upon wetlands and marshes. A mark-recapture study designed to measure juvenile tarpon growth in an altered mangrove habitat in Florida (USA) found that juvenile tarpon exhibited slow growth and emigrated at small sizes. The low scores on these metrics, in combination with a broad knowledge gap on the extent and condition of juvenile tarpon habitats in Florida, caused concern about the conservation prospects for tarpon and the fishery it supports. To provide information necessary to formulating an effective conservation plan for tarpon, we used citizen science to identify juvenile tarpon habitats and to characterize them as natural or altered (a first-level measure of direct, physical habitat change). A comparison of angler reports and habitat assessments with scientific field assessments showed that using anglers is an efficient and effective means of identifying juvenile tarpon habitats and providing a first-level assessment of habitat condition. This study provides a baseline for ongoing and future habitat conservation and restoration efforts for juvenile tarpon and other species that also use these habitats as nurseries.

Keywords Citizen science · Early life history · Habitat management · Recreational fisheries · Essential fish habitat

Introduction

Natural nearshore ecosystems are threatened worldwide by coastal development and degradation (Schmitter-Soto et al. 2017). The habitats within these systems play a crucial role as nursery habitats for fish and invertebrates due to their high primary and secondary

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productivity as well as structural complexity (Beck et al. 2001; Sathirathai and Barbier 2001; Nagelkerken et al. 2008; Teichert et al. 2017). The loss of these habitats worldwide - 50% of salt marshes (Brown 2006), 35% of mangroves (Valiela et al. 2001), 29% of seagrass meadows (Orth et al. 2006), and 85% of oyster reefs (Beck et al. 2011) - has directly impacted productivity and recovery of fish populations (Lotze et al. 2006; Barbier et al. 2011; Halpern et al. 2012; Schmitter-Soto et al. 2017). With 50% of the world's fish stocks fully exploited and 30% overexploited, depleted, or recovering (FAO 2016), and approximately 50% of fish and invertebrate landings coming from coastal waters (Lellis-Dibble et al. 2008), the preservation of these nursery habitats is paramount.

A species of particular concern is Atlantic tarpon (*Megalops atlanticus*), because juveniles are obligate users of mangroves and marsh systems as nursery habitat (Adams and Murchie 2015). Tarpon support an economically important recreational throughout their range in the Caribbean, sub-tropical and tropical Atlantic Ocean, and the Gulf of Mexico (Adams et al. 2013). Juvenile tarpon have highly vascularized swim bladders that allow them to survive in hypoxic or anoxic conditions by gulping air. This ability allows them to use habitats that exclude many predators and competitors (Seymour et al. 2008). These conditions are typically found in back-bay and creek habitats that characteristically have calm waters, a freshwater source with tidal influence and vegetative fringe (Adams et al. 2013). Unfortunately, these nursery habitats are susceptible to habitat loss and degradation through coastal development, which results in altered freshwater flows, changes in prey availability (Adams et al. 2009), a decline in vegetation (Lotze et al. 2006), or complete removal of the habitat. Despite the economic importance of tarpon and their dependence upon backwater habitats, little information is available on juvenile tarpon growth, survival, and emigration – all characteristics that can be used to evaluate nursery habitat quality (Beck et al. 2011), and thus estimate the impacts of habitat loss and degradation, as well as habitat restoration effectiveness.

Another challenge to nursery habitat conservation is a general lack of data on spatial coverage and locations of these habitats, and their condition relative to anthropogenic impacts. Although Beck et al. (2001) outline metrics to evaluate nursery habitat dependent on knowing the spatial coverage of these habitats, the spatial extent of these habitats is frequently unknown, as is the case for tarpon. In this approach, mapping is a valuable tool to estimate spatial coverage of nursery habitats (Sundblad et al. 2014). An alternative approach to nursery habitat identification that does not require knowledge of the spatial extent of habitats was proposed by Dahlgren et al. (2006). In either approach, however, habitats must be evaluated to determine their value as nurseries (Dahlgren et al. 2006; Tweedley et al. 2017).

Altered habitat can be broadly defined as a "change in land use or land cover that impacts the ecosystem" (Encyclopedia.com 2018), but definitions of habitat alteration differ among locations. Altered coastal habitats in Florida (USA) include mosquito control impoundments, retention ponds, golf courses, drainage ditch networks, dredging, and mangrove removal, all of which affect water quality, habitat complexity, and habitat continuity. In Florida, where nearly 80% of the human population live in the coastal zone (Rappaport and Sachs 2003), removal of mangroves for residential, commercial and industrial purposes has arguably had the biggest impact on these habitats (Duke 1997) and the 70% of commercially and recreationally important species that depend on mangroves (FWC 2018a). The loss of 44% of wetlands in Florida (FWC 2018b) has had similar impacts. In this study, we define habitat alteration as the direct, physical change of mangrove and marsh habitats – a type of alteration that is visible in field observations. We do so as a first-level assessment of habitat alteration that can be used concurrent with field determination of juvenile tarpon presence to provide a baseline estimate of juvenile tarpon habitat extent and condition.

The objectives of this study were twofold. First, to use metrics proposed by Beck et al. (2001) (growth, abundance, survival, emigration and movement within the system) to estimate the nursery habitat value for tarpon of an altered habitat in southwest Florida, for the dual purpose of providing a baseline for eventual comparison of multiple altered and natural habitats as well as for future habitat restoration. Second, to evaluate citizen science as an approach to identify habitats used by juvenile tarpon, and to categorize these habitats as natural or altered, as a means of addressing the data gap on spatial extent and condition of juvenile tarpon habitats in Florida. Given that resource management agencies typically lack funding to carry out these assessments, it's important to determine the extent to which citizen science can contribute to formulation of habitat conservation strategies.

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Methods

Juvenile habitat evaluation

The first component of this study was to use metrics outlined by Beck et al. (2001) to evaluate the nursery habitat value of Wildflower Preserve, an altered site in southwest Florida. We used mark-recapture to estimate juvenile tarpon growth, survival, population size and emigration of the entire study site to provide first such estimates for juvenile tarpon as well as a baseline for comparison to other sites (both natural and altered) and for comparison when this site is restored. We performed monthly seine net sampling with a mark-recapture component over an 18-month period. Movement between the ponds within the site was also studied using mark-recapture.

Study site

Wildflower Preserve (26.88°N, −82.31°W) is an 80-acre property located in Placida, Florida (USA), and is part of the Charlotte Harbor estuary watershed (Fig. 1). Prior to development as a golf course in the 1970s, the property was a mosaic of tidal creeks, wetlands, and ponds. The original ponds that remained after golf course construction are connected by a series of underground concrete culverts (30 cm diameter) to a single creek that provides tidal connection to the Charlotte Harbor estuary via Lemon Creek (Fig. 2). Flow through the 106 m long culvert connecting Lemon Creek to Wildflower Preserve is temporally restricted during daily low tides in the dry season (November–April), but fish passage is possible during dry season high tides. The culverts among ponds provide within-habitat connectivity throughout the year. The property was abandoned in 2006, and purchased for conservation protection in 2010 by Lemon Bay Conservancy, a local land trust, and is currently undergoing habitat restoration.

Juvenile tarpon were found in three ponds in Wildflower Preserve: Lemon Creek 1 (LC1), Lemon Creek 2 (LC2) and Tarpon Junction (TJ) (Fig. 2). LC1 is the second largest pond (1739 m^2), has the highest proportion of mangrove shoreline edge to total pond edge (88%) of the ponds (Table 1), and depth ranges from 0.6 m – 2.6 m. LC1 is separated from LC2 by a 6 m long underground culvert. LC2 is the closest pond to the estuary, and is connected to Lemon Creek by a culvert 106 m long. LC2 is the largest pond (4741 m^2), has the least percent mangrove shoreline (70.1%), and depth ranges from 1.9 m – 4.8 m. TJ connects to LC2 through a culvert that is 48 m long, is the smallest pond (323 m^2), has 78.6% mangrove shoreline, and depth ranges from 1.3 m – 2.3 m. TJ is the furthest distance from the culvert that connects to Lemon Creek. Flow was highest at the LC2 – Lemon Creek culvert connection during tidal shifts in the summer. We did not observe tidal flow at the culvert to TJ, even though water in the culvert was always sufficient depth to allow tarpon movement.

Fish sampling

Tarpon were sampled monthly from September 2012 through February 2014 in the three study ponds using a 194 m center bag seine (2.5 m high, 3.8 cm mesh), the most effective means for capturing juvenile tarpon in sufficient numbers for mark-recapture analysis. All sampling was conducted between 08:00 and 11:00 h. LC1 and TJ were netted once per sampling event, with the net encircling the entire pond. Because of the large area, LC2 required two net sets. For each sample at LC1 and TJ, the seine was deployed in a full circle around the periphery of the pond, ending at the starting point on shore. For LC2, the seine was set along approximately ½ of the shoreline and then through the center of the pond, with each of the two net sets sampling ½ of the pond. The net was set using a 4.3 m aluminum jon boat powered by an 80 pound thrust electric trolling motor, then pulled manually onshore. Once the center bag was brought to shore, juvenile tarpon were collected from the net and placed into floating mesh bags within the pond while the seine net was cleared of fish. Tarpon were then transferred to aerated 43-l coolers for a maximum of 10 min before processing. In addition to monthly fish sampling, we recorded salinity, temperature and dissolved oxygen at 0.5 m below the surface and just off the bottom of each of the three study ponds using a YSI Pro DSS (YSI Incorporated) for twelve (September 2013 – August 2014) monthly samplings (except for May 2014).

Mark-recapture

To provide data necessary to estimate growth, abundance (population size in this study), survival, and emigration for the entire Wildflower Preserve study site, individuals were marked during all seining events using two methods: genetic fingerprinting from a fin clip if

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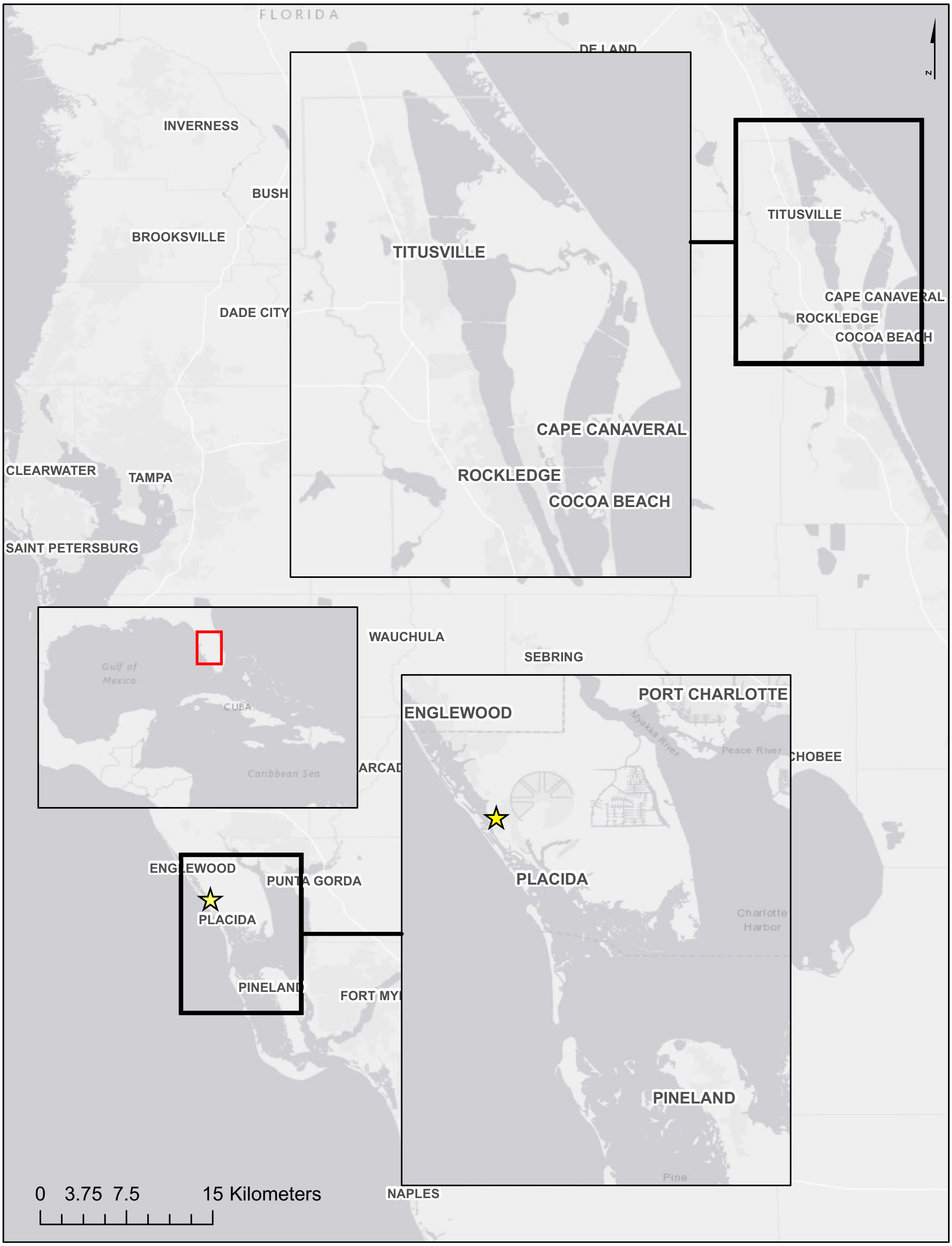

Fig. 1 Map of east (Indian River Lagoon) and west (Charlotte Harbor) coast test regions for habitat identification and characterization. Wildflower Preserve, denoted by a star, is found within the Charlotte Harbor test region (created in ESRI ArcMap)

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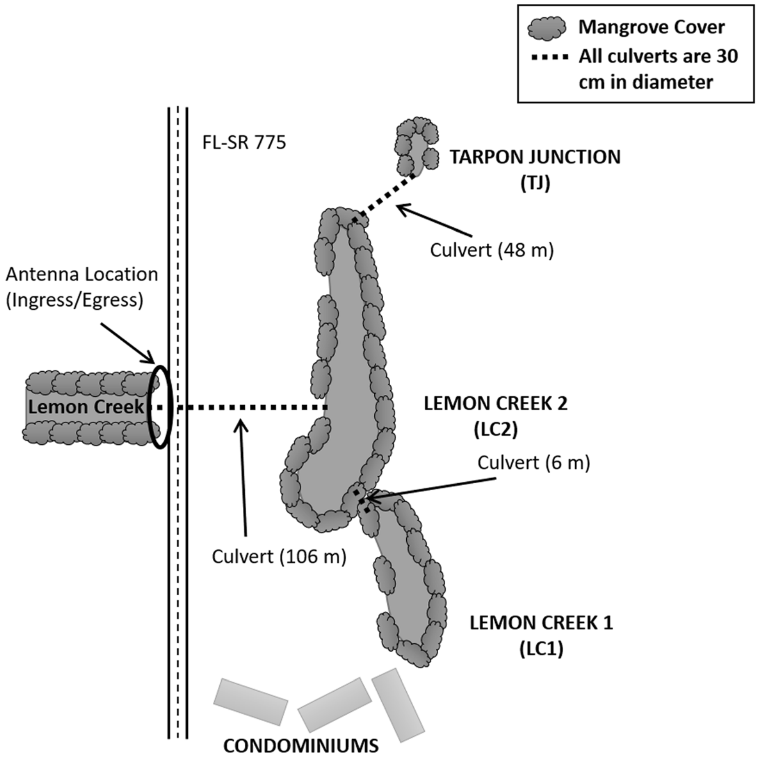

Fig. 2 Not to scale - Wildflower Preserve consists of 3 study ponds (Lemon Creek 1 – LC1, Lemon Creek 2 – LC2, and Tarpon Junction - TJ) that are connected by a series of underground culverts. The culvert from LC2 to Lemon Creek provides the sole connection to the estuary and is equipped with a stationary antenna to track emigration

tarpon were < 190 mm SL; and Passive Integrated Transponder (PIT) tags inserted into the abdominal cavity if ≥190 mm SL. Each tarpon was first scanned for a previously implanted PIT tag, then standard and fork length were measured to the nearest 1.0 mm. If the tarpon was already marked with a PIT tag, the tag identification number was recorded prior to releasing the fish. All fish were released into the pond where they were captured.

Each tarpon ≥190 mm SL that had not been previously tagged was implanted with a 23 mm PIT tag. A 3 mm incision was made using a No. 15 scalpel posterior and ventral to the pectoral fin, and the tag was inserted into the abdominal cavity (Adams et al. 2006). The PIT tag number was recorded and the fish was then returned to the aerated cooler before being released into the pond where it was captured.

Table 1 Measurements of pond area, pond perimeter, percentage mangrove cover and mangrove shoreline for three study ponds (Lemon Creek 1, Lemon Creek 2 and Tarpon Junction) at Wildflower Preserve

	Lemon Creek 1	Lemon Creek 2	Tarpon Junction	Total
Pond Area (m^2)	1739	4741	323	6803
Pond Perimeter (m)	186.6	407.7	85.1	
Mangrove Cover (%)	88.3	70.1	78.6	
Mangrove Shoreline (m)	164.8	285.4	66.9	517.1

For genetic sampling, the tip of the upper lobe of the caudal fin was cut with scissors and placed into a vial of 20% ethanol solution labeled with a unique fin clip number. Atlantic tarpon can be genetically identified to the individual level (Seyoum et al. 2008). Samples were processed and analyzed by the Florida Fish and Wildlife Conservation Commission's Molecular Genetics Laboratory at the Fish and Wildlife Research Institute in St. Petersburg, Florida. All fish without a PIT tag, even over the tagging threshold of 190 mm, were fin-clipped since they could have been previously captured below the tagging threshold.

To provide recaptures that would allow an estimate of emigration, a PIT tag antenna to passively monitor for juvenile tarpon implanted with PIT tags was placed at the western side of the culvert to Lemon Creek prior to the start of seining, which provided the sole connection between the study site and the estuary (Fig. 2). Antenna components included a solar panel, two 6-V batteries, a junction box, a computer, a tuning box and an inductor

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coil constructed from 20 awg copper wire (Fig. 3), following Barbour et al. (2011). The inductor coil spanned the creek creating a vertical loop 0.3 m from the bottom that was 3.2 m wide and 0.65 m tall. The read range (distance from the antenna at which PIT tags were detected) was 30 cm. Given that the antenna wire was on the top, bottom, and sides of the creek, the read range covered the entire water column. Tagged juvenile tarpon that were detected by the antenna were identified as emigrants that migrated from the juvenile habitat into adjacent estuarine habitats. Downloads of antenna recapture data were conducted monthly.

Tarpon growth rates

Growth rates were derived from the physical recaptures of known individuals. Standard length and fork length were significantly related ($r^2 = 0.99$; $y = 0.92x$; $p < 0.001$), therefore fork length (FL) was used for all growth estimates. The difference in days between capture and recapture dates were used to determine the growth rate (mm/day) of fish and calculated as the change in length for recaptured fish per day:

$$Growth\ rate = \frac{\Delta FL(mm)}{\Delta t(day)} \quad (1)$$

Growth rates of PIT tagged and fin clipped fish were charted to determine if growth varied as a function of tarpon size or mark-recapture method. Tarpon had the potential to be recaptured during the 17 subsequent samplings following the initial month of capture. Monthly (18) histograms of individuals captured in all three ponds over the course of the study were used to look for a modal trend in fish size over time.

Tarpon movement

Recaptures in the seine net during sampling were used to determine movement among ponds. PIT-tagged fish that were detected at the Lemon Creek antenna were counted as emigrants. Because of the potential for juvenile fish to expand their home range while still returning to the nursery habitat (Barbour et al. 2014), individuals were considered emigrants in their last month of detection when multiple months of antenna encounters occurred. This is to ensure that the fish had truly exited the data Wildflower Preserve system.

Estimates of survival and population size

A Cormack-Jolly-Seber (CJS) open population model was used to estimate apparent annual survival and calculate monthly estimates of population size from mark-recapture data. The CJS model assumes 100% tag retention for the duration of the study, equivalent survival and catchability for marked and unmarked individuals, and a constant study area. The CJS model accounts for changes in population within the system due to death, birth (not a factor in our system), immigration and emigration. In the CJS model, birth and immigration are treated as equivalent, and death and emigration as equivalent.

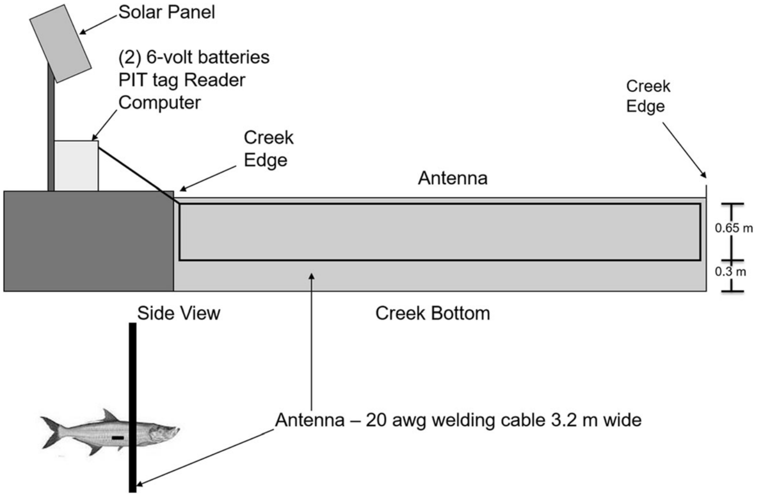

Fig. 3 Not to scale – The stationary antenna used to track emigration from Wildflower Preserve is 3.2 m wide X 0.65 m high and has a read range of 0.3 m. Components include: copper wire to create the inductor coil, a PIT tag reader computer, (2) 6-V batteries, and a solar panel

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The models for this study were selected to allow for fixed and varying capture probability and survival following two different approaches: seasonal changes based on four seasons (spring, summer, fall, winter) and two seasons (wet/dry). Survival (*phi*) and capture probability (*p*) of juvenile tarpon were estimated using program MARK (version 6.1; White and Burnham 1999). Models were given an Akaike Information Criterion (AIC) value to estimate relative quality of the model. The most parsimonious model was used to estimate population size (Akaike 1973; Arnold 2010) over the 18 month study.

The best fit model was used to assess potential variation in survival as a function of season. This model pooled 2 years into wet (May–October) and dry (November–April) seasons (Kahl 1964; Davis and Ogden 1997). Capture probabilities (*p*) from the accepted model were used to estimate population size (N_i) from the juvenile tarpon capture history data. Total population size was estimated by dividing the monthly captures (r_i) by the maximum likelihood estimate of the capture probability and the upper and lower 95% confidence intervals of the best fit model.

Habitat identification and characterization

An essential component to evaluating nursery habitat is that it is a comparative process. Beck et al. (2001) assigned a nursery habitat's value as a relative measure – based on the metrics of growth, survival, density, and emigration – as compared to other habitats. Therefore, the next step in evaluating the relative value of not only Wildflower Preserve, but of juvenile tarpon habitats in general, is to identify the spatial extent of these habitats. The metrics obtained from Wildflower Preserve provided the first baseline assessment of juvenile tarpon growth in an altered habitat, but how do these metrics compare to other habitats, whether natural or altered? Further, a challenge with assigning nursery habitat value for tarpon is that the extent of likely nursery habitats is unknown. Important to designing a conservation strategy to protect and restore habitats, as appropriate, is an assessment of habitat condition. This information for juvenile tarpon habitats is lacking entirely for the state of Florida. Therefore, to provide a framework for future nursery habitat evaluation, and to provide information essential for formulating a habitat conservation strategy, we determined the extent that citizen science is a viable approach for identifying likely juvenile tarpon nursery habitats and providing first-level estimates of habitat condition.

Habitat identification

We used a citizen science approach (Delaney et al. 2008) to identify juvenile tarpon habitats in Florida (USA). Beginning in January 2016, we used social media, print media, and presentations at fishing clubs to ask anglers and professional fishing guides to report juvenile tarpon locations. All sites had to be visited within the previous 2 years and include tarpon <30 cm FL (< 1 year old; Crabtree et al. 1997) to ensure that sites were true nursery habitats and not a secondary nursery used by older juveniles. The anglers were asked to provide a classification of the site as "natural" or "altered". For the classification we did not provide a definition of altered or natural, instead relying on the anglers to characterize the sites. However, examination of angler classifications revealed that all classifications were based on the level of physical habitat alteration (e.g., mangrove removal, dredging, ditching) at the site. The data were transcribed into a database and each location was given a Habitat Mapping Identification number (HMID). Because of the sensitive nature of the information provided (recreational anglers are hesitant to share fishing locations), HMIDs are used instead of latitude and longitude when sharing data with others.

Habitat characterization

With juvenile tarpon habitat locations identified by anglers, the next step was to characterize these sites using established mapping methods. To accomplish this, we selected two regions to test a mapping-based habitat characterization matrix: Charlotte Harbor (CH) on the Gulf of Mexico coast, and the northern section of Indian River Lagoon (NIRL) on the Atlantic Ocean coast (Fig. 1). These specific regions were chosen because of the robust habitat datasets provided to us by Florida Fish and Wildlife Conservation Commission's GIS Laboratory. In order to generate a list of characteristics with importance to tarpon nursery habitat, we collaborated with habitat suitability modelers at the Florida Fish and Wildlife Conservation Commission Fish and Wildlife Research Institute (FWRI). We followed similar guidelines utilized with previous work with spotted seatrout (*Cynoscion nebulosus*) in Charlotte Harbor (Rubec et al.

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2001), which used a combination of catch data in specific habitats and environmental data to generate a habitat characteristics list.

The variables we used to characterize habitats included creek sinuosity, habitat connectivity, percent mangrove cover and percent marsh cover as a measure of altered or natural landscape. Access and depth variability were chosen because of their mention as critical nursery habitat characteristics in Adams et al. (2013) and Duffey (2012), and the final characteristic was a determination of the habitat as not altered ("none"), experienced "some" alteration of the landscape, or was completely altered ("all"). The list included habitat components that are measured either using GIS software or in the field, and to standardize the procedure each characteristic was given a three-point ranking system (Table 2).

GIS-based characterization

We used GIS maps provided by FWRI to rank two of the characteristics (creek sinuosity and habitat connectivity) from the angler reported locations. Tidal creeks often have a natural curvature and the presence or absence of this feature helped us to better determine if the site has been altered. A variation of the methods of Aswathy et al. (2008) was used by mapping creek sinuosity using a centerline from the mouth of the creek to the point of the nursery habitat. The creek was then assessed as "no" sinuosity if it was channelized with little to no deviation of the banks of the creek across the centerline, "some" sinuosity if the banks of the creek crossed the centerline 10–50% of the length of the line, or "all" sinuous if the banks crossed the centerline >50% of the length of the line. We included habitat connectivity to accommodate the importance of the coastal habitat mosaic (aka seascape) (Adams et al. 2006; Nagelkerken et al. 2015) that must be addressed as we move toward a more complete understanding of nursery habitats in the coastal ecosystem (Litvin et al. 2018). We used GIS maps to estimate the amount of adjacent habitat that is natural for two reasons: larvae coming into the system will have to traverse these habitats and they may be deterred or suffer higher mortality if they have to pass through a developed area; and emigrants leaving the nursery habitat will likely have higher survival if habitat appropriate for the next ontogenetic stage is adjacent to the nursery habitat as part of an intact coastal habitat mosaic (habitat fragmentation can negatively impact the survival of emigrants (Fischer and Lindenmayer 2007). GIS resources were used to evaluate the potential for tarpon to access the nursery habitat. We often find juvenile tarpon in locations that are ephemerally connected (e.g. golf course ponds, mosquito impoundments), which provide a physical barrier from larger predators entering the system, but it also inhibits the ability for tarpon to leave the system. GIS maps also gave us an initial ranking of access and scale of alteration that would be compared in the field for final assessment. Limited or shallow access can be an advantage for juvenile fish as a deterrent for predators from entering nursery habitats. Far reaches of tidal creeks are often isolated during dry seasons, but it is unclear if this is a beneficial trait for nursery habitats. Access points for fish passage were located in GIS and the amount of access was verified in the field.

Field-based characterization

Each location provided by anglers within the two test regions was groundtruthed using five of the seven habitat characteristics generated for juvenile tarpon (3 field only, 2 combination field/GIS) (Table 2). Depth variability, percent mangrove cover and percent marsh cover were ranked solely based on field observation while access and scale of alteration were confirmed after consulting with the GIS ranking. Trained technicians performed field assessments at each location as close to the reported coordinates as possible. When anglers were available, they accompanied scientists in the field to provide site specifics that were difficult to measure (i.e. exact location tarpon were observed, water depth). The accessibility rank that was assigned to each site using GIS was verified in the field. Are range of depths seems to be beneficial for juveniles that spend multiple seasons in a nursery habitat by providing a temperature refuge and protection from wading birds (Kushlan 1976). Depth was the most difficult to measure because of visibility in the water column found in these specific habitats is typically very low. The technicians recorded the minimum and maximum depths found at the site at the time of visit, and assigned the appropriate depth-variability category for range of depths found at the site (<0.5 m, 0.5–3 m, >3 m). It's important to note that the ranking system is the range of depths and **not** the actual depth. For example, a site with a depth that is uniform depth would be ranked as <0.5 depth variability, whereas a site for which the depth ranged from 0.2 m to 6 m

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Table 2 List of Habitat Characteristics with description, how they were assessed (GIS or Field) and three potential ranks for each characteristic

Habitat Characteristic	Method Assessed	Description	Ranking	Ranking Description
Creek Sinuosity	GIS	Amount of curvature in the creek structure	None, Some, All	None – a straight line; Some – 10-50% deviation of mid-streamline from center; All - >50% deviation of mid-streamline from center (Aswathy et al. 2008)
Habitat Connectivity	GIS	Amount of adjacent habitat available to emigrants of the nursery habitat	None Nearby, Some Nearby, Many Nearby	None Nearby – no natural habitat within 100 m; Some Nearby – 20-40% vegetated habitat within 100 m; Many Nearby – >50% adjacent vegetated habitat within 100 m for emigrants
Access	GIS/Field	Habitat accessibility at various tides	Open, Tidal, Ephemeral	Open – accessible at all tides; Tidal – accessible at least once daily or every other day; Ephemeral – intermittently connected or connected only during episodic events (e.g., flooding, storm surge)
Depth Variability	Field	Range of water depth within the site	<0.5 m, 0.5 – 3 m, >3 m	Minimum and maximum depths within the site
% Mangrove Edge	Field	Ratio of mangrove edge to shoreline	<25%, 26–74%, >75%	Percentage of shoreline that is vegetated by mangroves
% Marsh Edge	Field	Ratio of marsh edge to shoreline	<25%, 26–74%, >75%	Percentage of shoreline that is vegetated by marsh grass
Alteration	GIS/Field	Amount the habitat has been anthropogenically affected	None, Some, All	None – completely natural; Some – some alteration at site; All – site is completely altered

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would be categorized as >3 m. Technicians then estimated the amount of vegetative edge (both mangrove and marsh) and recorded the range of percent cover. This is a direct measure of landscape cover as well as the amount of fringing vegetation available for juvenile tarpon in the nursery habitat. Both GIS-based and field-based characteristics aided us in our final determination of a site as natural (none), partially altered (some), or fully altered (all). As previously stated, since this was an examination of citizen science contribution to habitat identification and condition assessment, in this study habitat categorization of altered vs. natural was based solely upon physical alteration of the habitat at the site (e.g. mangrove removal, ditching and dredging). In other words, can citizen scientists adequately categorize these habitats in terms that can be applied to conservation?

Results

Juvenile habitat evaluation

A total of 941 unique juvenile tarpon was captured in seines and marked – 219 implanted with PIT tags and 722 fin clipped for genetic fingerprinting: 706 juvenile tarpon were marked in LC 1, 152 in LC 2, and 83 in TJ (Table 3). A total of 99 recaptures occurred – 26 PIT tag recaptures and 73 fin clip matches, approximately 10% for both methods, which suggests similar capture probability between tagged and fin clipped fish. There were three instances (out of 99) of genetically matched fish that failed to retain their tag.

Capture rates varied monthly, with high captures ($n = 75–184$/month) from November 2013 to March 2014, very low captures during the summer ($n = 3–5$/month), and increased captures the following winter ($n = 15–49$/month), but not reaching the levels found the first winter (Fig. 4).

Environmental data

Bottom salinity was typically highest in LC2, then LC1 and TJ, and was stratified in all ponds (Supplemental Fig. 1). Temperature showed the same seasonal pattern in each pond and at the surface and bottom: temperature ranged from 20 to 25 °C in the dry season (November – April) to 25–32 °C in the wet season (May – October) (Supplemental Fig. 1). Dissolved oxygen varied monthly between all three ponds, and were low throughout the study period with 86% of readings showing hypoxic conditions (under 2 mg/L) (Vaquer-Sunyer and Duarte 2008) (Supplemental Fig. 1).

Growth

Overall, 34% of 99 recaptured fish exhibited negative or no growth. Mean daily growth was calculated at mean = 0.07 ± 0.04 SE mm/day ($n = 99$). Time at large ranged from 14 to 484 days with an average of 92 days (± 0.46 SE). Growth rate did not differ as a function of fish size ($y = 0.00026x + 0.12$, $p = 0.77$, $n = 96$) (Fig. 5), thus there was no difference in growth rate between larger (PIT-tagged) and smaller (fin-clipped) fish. Length-frequency histograms showed little modal progression over the 18-month sampling period (Fig. 4), further indicating little to no growth at the population level.

Movement within the system

Of the recaptured tarpon, 89% were recaptured in the same pond where they were initially tagged (Table 4). Ninety-nine percent of tarpon recaptured in LC1 were originally captured in LC1. However, most recaptures of tarpon initially tagged in LC2 (54%) and TJ (80%) occurred in LC1, suggesting directed movement toward LC1. The highest catches and recaptures consistently occurred in LC1, and lowest in TJ (Table 3).

Table 3 Initial capture and recapture locations of juvenile tarpon for three study ponds (Lemon Creek 1, Lemon Creek 2, Tarpon Junction) and density of juvenile tarpon per mangrove shoreline (m) and pond area (m^2) at Wildflower Preserve

	Lemon Creek 1	Lemon Creek 2	Tarpon Junction	Total
Initial Capture	706	152	83	941
Recaptures	91	7	1	99
Density (Mang Shore)	4.284	0.533	1.241	
Density (Pond Area)	0.406	0.032	0.257	

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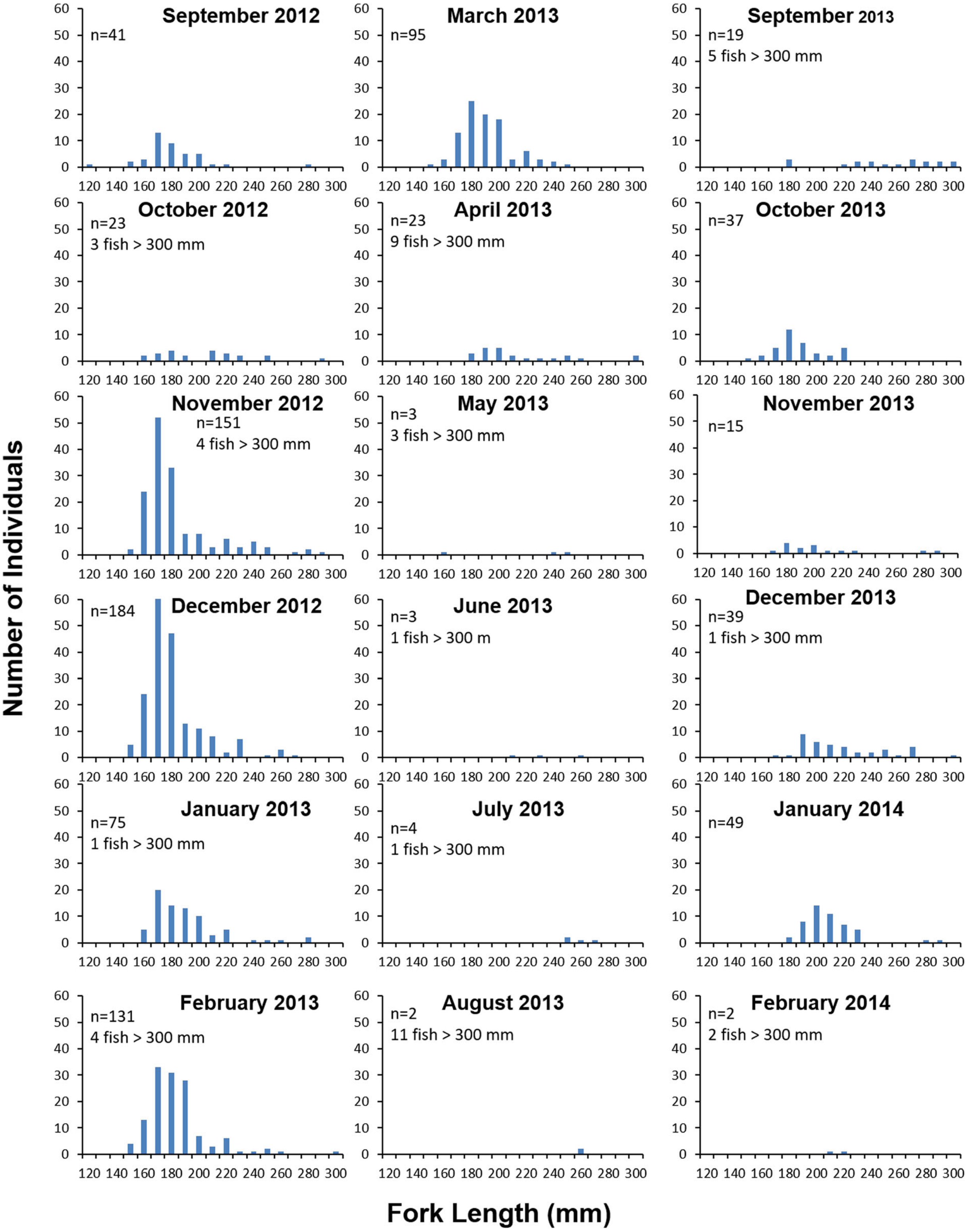

Fig. 4 Monthly histograms of fork length (mm), separated into 10 mm bins for juvenile tarpon captured in Wildflower Preserve

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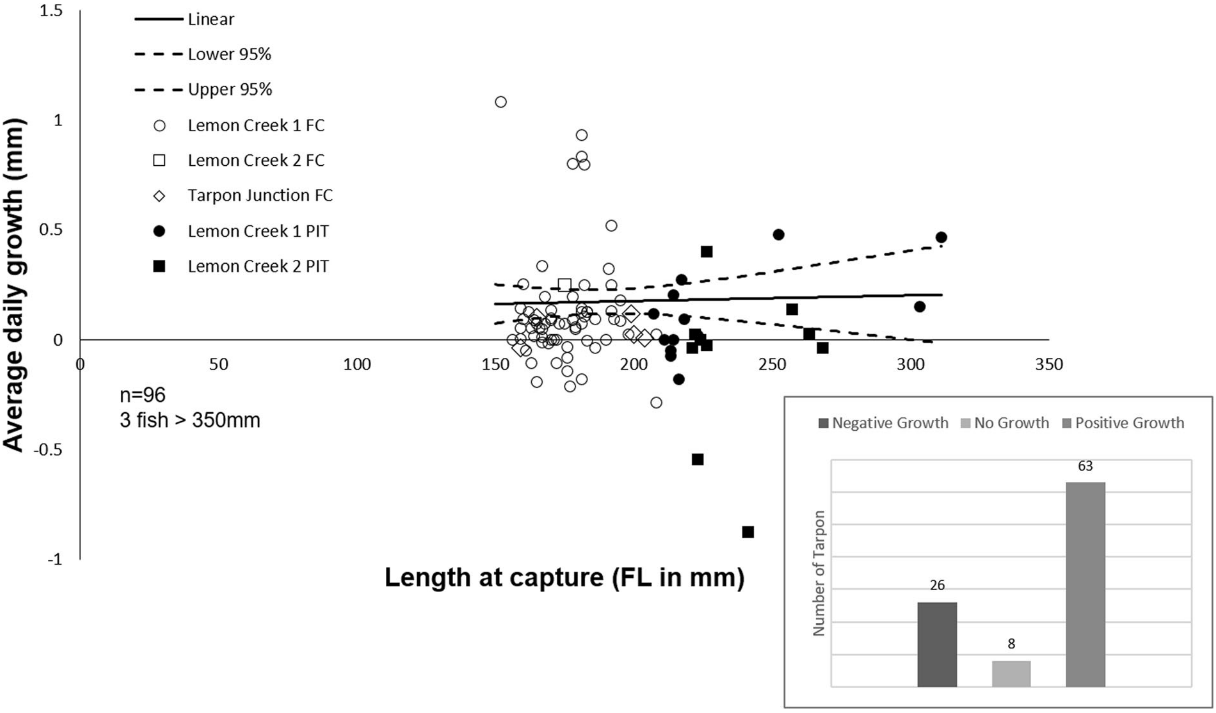

Fig. 5 Average daily growth (mm) as a function of length at capture for juvenile tarpon at Wildflower Preserve categorized by type of mark-recapture (PIT = PIT tag; FC = fin clip) and study pond. Regression line is fit to all daily growth rates ($y = 0.00026x + 0.12$, $p = 0.77$). Inset is the number of individuals that experienced negative growth, no growth, or positive growth

Emigration

Of 219 PIT-tagged juvenile tarpon, 59 (27%) were detected by the antenna. Of the 59 detected by the antenna, seven were also recaptured by seine, prior to antenna detection, suggesting emigration was unidirectional as opposed to temporary as observed for juvenile snook, whereby individuals left and then reentered the system prior to the final emigration event (Barbour et al. 2014). Although emigration was possible in all months, most detections occurred in summer and early fall (Fig. 6b), which coincides with both age-1 emigration and the influx of new recruits.

Estimates of population size

Seven models were run which included all variations of constant, four season (spring, summer, fall winter) and two season (wet/dry). Only models with ΔAIC < 2 were used to estimate population size, and from these three models only one was deemed appropriate because it was the most parsimonious (Anderson 2008) (Table 5). The selected model is as follows:

Constant survival (.) and two seasonal (wet/dry) changes in probability of capture (lower in wet and higher in dry). This model showed a sharp increase in juvenile tarpon population size in December/January

Table 4 Percentage of movement of juvenile tarpon in all three ponds (Lemon Creek 1, Lemon Creek 2, Tarpon Junction) at Wildflower Preserve between initial mark and recapture. Bold numbers denote capture and recapture in the same pond, sample size in parentheses

	Recapture Location		
Tag Location	Lemon Creek 1	Lemon Creek 2	Tarpon Junction
Lemon Creek 1	**99% (80)**	1% (1)	0% (0)
Lemon Creek 2	54% (7)	**46% (6)**	0% (0)
Tarpon Junction	80% (4)	0% (0)	**20% (1)**

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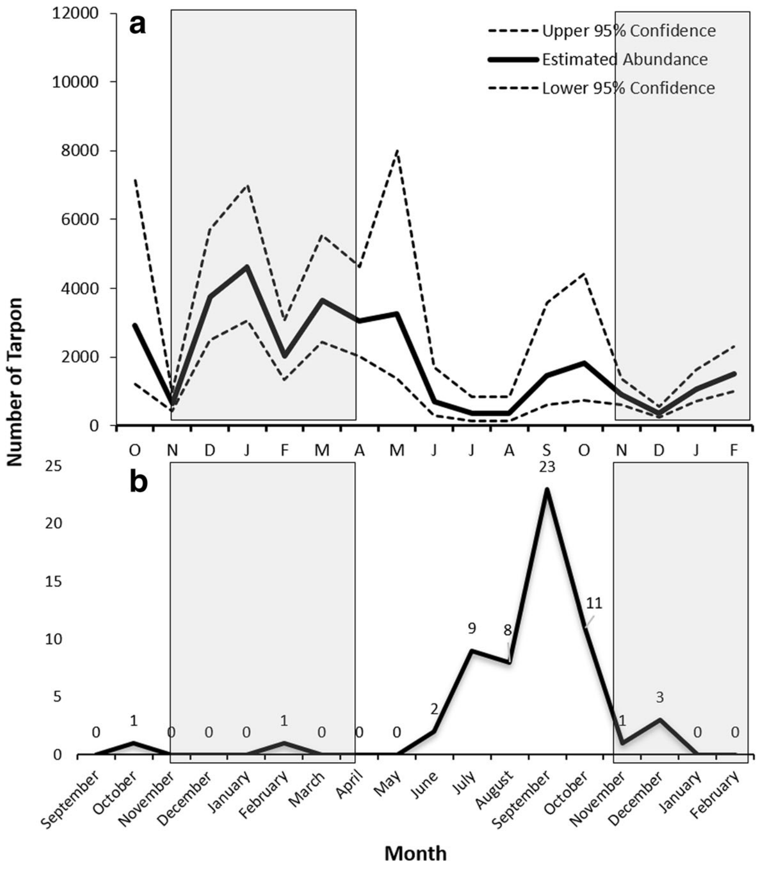

Fig. 6 **a** Monthly population size estimates of juvenile tarpon at Wildflower Preserve with upper and lower confidence intervals for the best fit model (two season phi(.)p(wet/dry), see Table 6); (**b**) monthly detections of individual PIT tagged juvenile tarpon at the stationary antenna at Wildflower Preserve. If an individual was detected during more than 1 month, only the final detection was used as a measure of emigration

(~4000–5000 individuals) and the lowest population size in July/August (~250–350 individuals) (Fig. 6a). These numbers correspond to tarpon densities per meter of mangrove shoreline of 9–11 in December/January down to 0.5–0.7 in July/August. Apparent annual survival was 0.007 (95% CI: 0.001–0.033) (Table 6).

Table 5 ΔAIC scores for all manipulations of four season (season) and two season (wet/dry) variations of phi (apparent survival) and p (probability of capture) for juvenile tarpon at Wildflower Preserve

Model	ΔAIC	No. of Parameters
Phi(.)p(wet/dry)	0.0	3
Phi(season)p(season)	0.86	8
Phi(wet/dry)p(wet/dry)	1.94	4
Phi(.)p(season)	2.74	5
Phi(.)p(wdwd)	3.02	5
Phi(wdwd)p(wdwd)	5.67	8
Phi(.)p(.)	5.82	2
Phi(wet/dry)p(.)	6.06	3
Phi(wdwd)p(.)	7.03	5
Phi(season)p(.)	8.71	5

Habitat identification and characterization

Habitat identification

Over the course of 22 months, 224 juvenile tarpon locations were reported by anglers – 15 in the Charlotte Harbor (CH) test region (four natural, 11 altered), 19 in

Table 6 Estimates of constant apparent annual survival (phi) and probability of capture (p) with respect to two season (wet/dry) variation for juvenile tarpon at Wildflower Preserve derived from MARK

Parameter	Est.	LCI	UCI
Phi	0.007	0.001	0.033
P(wet)	0.014	0.006	0.035
P(dry)	0.041	0.027	0.062

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the NIRL test region (four natural, 15 altered), and the rest in other parts of the state (Table 7). Four sites in the NIRL test region were supplied by FWC's Fisheries Independent Monitoring section rather than by anglers, so were not used in the citizen science – scientific assessment comparison. Therefore, a total of 31 sites in the test regions were visited by field technicians, most of which were described by anglers as altered, to provide a scientific assessment of the habitat characteristics (Table 7). When angler habitat assessments were compared to scientist field assessment, anglers were able to accurately categorize habitat as natural or altered based on anthropogenic physical changes to the site 84% (26/31) of the time (Table 7). All of the discrepancies occurred in the NIRL region, which is a more anthropogenically altered region than CH. Of the four opposing assessments, two were designated altered and two were designated natural by anglers with the opposite designation recorded by the field technician.

Discussion

A major challenge to the framework of nursery habitat assessment proposed by Beck et al. (2001) is that the data required to properly assign nursery habitat value is unobtainable for many species and locations. Indeed, Dahlgren et al. (2006) proposed a modification of the Beck et al. (2001) approach by suggesting "effective nursery habitat" that did not require mapping data. Dahlgren et al. (2006), focusing on coral reef fishes and habitats, stated that obtaining such mapping data for most locations was not realistic, in part because a large portion of coral reef habitats were in nations with considerably limited resources. The same can be said for non-reef fishes and habitats, even in nations with more resources. Indeed, in Florida there are presently no maps depicting habitats essential for tarpon, much less most other economically important species (Rubec et al. 2001). Moreover, the single-habitat approach highlighted by Beck et al. (2001) and Dahlgren et al. (2006) is inadequate in that most species rely upon the connectivity provided by a coastal habitat mosaic (aka seascape) to complete early life stages (Adams et al. 2006; Nagelkerken et al. 2015). These shortfalls have important consequences for conservation (Lotze et al. 2006).

With the known challenges to nursery habitat identification and conservation in mind, this study used a mixed approach to evaluate juvenile habitats using conventional metrics (Beck et al. 2001) and examine an alternative to obtain important habitat data, with the overall goal of obtaining information directly applicable to fish and habitat conservation. This study applied the traditional metrics of growth, survival, abundance (examined as population size in this study), and emigration to evaluate Wildflower Preserve (HMID 221, Table 7), an altered juvenile tarpon habitat classified as altered by an angler and verified through our habitat characteristics. Based on low growth rates, and subsequent small estimated size at time of emigration, this altered site was deemed to be of poor nursery quality. Since a notable portion of Florida's wetland and mangrove habitats, upon which juvenile tarpon depend (Adams and Murchie 2015), have been degraded or lost (FWC 2018b), the results from Wildflower Preserve highlighted concerns about knowledge gaps for tarpon: namely, that the spatial coverage and condition of juvenile tarpon habitats in Florida was unknown. This spurred the second phase of research that successfully used citizen scientists to identify locations used by juvenile (<30 cm FL) tarpon and to provide first-level habitat characterization as natural or altered. With this success, next steps are to: replicate the Wildflower Preserve study in sites identified by citizen scientists to evaluate habitats as categorized in this study (altered vs natural); expand the citizen science approach to identify more habitats; use the information provided by this study to inform a GIS-based approach to determine if remote mapping can replicate citizen science results; use the data from this study in an actionable knowledge framework (Adams 2017) to incorporate habitat into fisheries management of tarpon.

The very low growth rate observed in this study (0.07 ± 0.04 SE mm/day) suggests that Wildflower Preserve is not a high-quality nursery habitat. Although previous studies of juvenile tarpon growth rate suffered from low sample size, all found higher growth rates than were found in this study: 0.88 mm/day in captivity (Breder 1944); 1.44 mm/day in September and 0.72 mm/day in October in a Florida mangrove pond (Breder 1944); 1.0 mm/day in manmade ditches (Moffett and Randall 1957); and 1.0 mm/day in a Georgia salt marsh (Rickards 1968). Similarly, juvenile snook in Florida that were spawned in the same season and used similar habitats to juvenile tarpon grew at a rate of 0.6–0.9 mm/day (McMichael et al. 1989). Juvenile tarpon in an altered South Carolina impoundment had the most similar growth rate to this study, at 0.14 mm/

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Table 7 Habitat characteristic results for the Charlotte Harbor (CH) and Indian River Lagoon (IRL) test regions; angler assessments that differed from scientist assessments are denoted in **bold**. HMID *221 is Wildflower Preserve

HMID	Region	Sinuosity	Connectivity	Max Depth (m)	Min Depth (m)	Depth Var (m)	Mangrove Edge	Marsh Edge	Alteration	Access	Angler Assessment
2	CH	All	Some Nearby	3	0.5	0.5–3	26–74%	<25%	All	Tidal	altered
17	CH	All	Many Nearby	3	1	0.5–3	26–74%	<25%	Some	Open	altered
87	CH	All	Many Nearby	2	0.5	0.5–3	<25%	26–74%	All	Tidal	altered
105	CH	Some	Many Nearby	1	0.5	0.5–3	>75%	<25%	Some	Tidal	altered
106	CH	Some	Many Nearby	1.5	0.5	0.5–3	26–74%	<25%	Some	Tidal	altered
210	CH	Some	Many Nearby	2.5	0.5	0.5–3	26–74%	<25%	Some	Tidal	altered
*221	CH	Some	Some Nearby	4	0.5	>3	>75%	<25%	Some	Tidal	altered
222	CH	All	Many Nearby	2.5	0.5	0.5–3	>75%	<25%	Some	Open	altered
224	CH	None	None Nearby	3	0.5	0.5–3	26–74%	<25%	All	Ephemeral	altered
225	CH	None	None Nearby	5	0.5	>3	<25%	<25%	All	Ephemeral	altered
229	CH	All	Many Nearby	2	0.5	0.5–3	>75%	<25%	None	Tidal	natural
230	CH	All	Many Nearby	1.5	0.5	0.5–3	>75%	<25%	None	Tidal	natural
231	CH	All	Many Nearby	1.5	0.5	0.5–3	>75%	<25%	None	Tidal	natural
232	CH	All	Many Nearby	1.5	0.5	0.5–3	>75%	<25%	None	Tidal	natural
247	CH	None	None Nearby	2.5	0.5	0.5–3	<25%	<25%	All	Tidal	altered
33	IRL	Some	Many Nearby	1	0	0.5–3	26–74%	<25%	All	Open	**natural**
63	IRL	None	Some Nearby	0.5	0.25	<0.5	<25%	>75%	All	Open	natural
64	IRL	None	Some Nearby	1	0.5	0.5–3	<25%	>75%	Some	Open	not recorded
66	IRL	None	Many Nearby	0.5	0.25	<0.5	>75%	<25%	None	Open	natural
67	IRL	None	Many Nearby	0.5	0.25	<0.5	>75%	<25%	Some	Tidal	**natural**
98	IRL	Some	Many Nearby	0.5	0.25	<0.5	>75%	<25%	None	Open	natural
100	IRL	None	None Nearby	1	0.25	0.5–3	<25%	<25%	All	Ephemeral	altered
115	IRL	None	None Nearby	1	0.25	0.5–3	<25%	<25%	All	Open	not recorded
119	IRL	None	Some Nearby	0.5	0.25	<0.5	<25%	<25%	All	Open	not recorded
126	IRL	None	Some Nearby	0.5	0.25	<0.5	<25%	>75%	All	Open	altered
127	IRL	All	Some Nearby	0.5	0.75	<0.5	>75%	<25%	None	Open	**altered**
130	IRL	None	Some Nearby	1	0.25	0.5–3	<25%	<25%	All	Ephemeral	altered
133	IRL	Some	Many Nearby	1	0	0.5–3	26–74%	<25%	All	Open	altered
149	IRL	None	None Nearby	3	0.5	0.5–3	<25%	>75%	All	Open	altered
154	IRL	Some	Some Nearby	0.5	0.25	<0.5	>75%	<25%	All	Open	altered
155	IRL	Some	Many Nearby	0.25	0	<0.5	>75%	<25%	None	Open	**altered**
220	IRL	All	Many Nearby	0.5	0.25	<0.5	<25%	26–74%	Some	Open	altered
239	IRL	Some	Many Nearby	2.5	0.5	0.5–3	<25%	26–74%	Some	Open	altered
244	IRL	All	Many Nearby	2	0.5	0.5–3	<25%	<25%	All	Open	altered

day (Mace et al. 2018), but the authors did not measure environmental parameters that might explain the low growth rate other than to identify the habitat as a man-made impoundment system.

Poor growth in the nursery habitat could be attributed to many factors. High density in the nursery habitat is beneficial until it reaches a threshold that results in poor growth (Bjornsson 1994). Refstie (1977) studied post-larval rainbow trout (*Oncorhynchus mykiss*) at varying densities and reported significantly diminished growth at high densities. For juvenile tarpon, during the dry season, ephemeral links to nursery habitats can be temporarily severed as water levels fall, resulting in less available habitat while simultaneously trapping juveniles in the system. This study found 0.5–0.7 juvenile tarpon per m of shoreline in July/August (wet season)

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and much higher densities of 9–11 juvenile tarpon per m of shoreline during the dry season (December/January). As a comparison, a study in a nearby natural creek system found juvenile snook densities of 0.02–0.1 per m of mangrove shoreline in the wet season (early summer) (Brennan et al. 2008). In this study, connectivity to the estuary during the dry season was limited to high tides due to low natural, seasonal water levels, and the apparent natural pattern of ontogenetic emigration to occur during wet season, likely created a situation that resulted in higher densities in a limited amount of space, which can contribute to slow growth (Matthews and Marsh-Matthews 2003). Although not measured in this study, prey availability in the nursery habitat also influences growth (Jones 1986).

The estimated survival rate found in this study (0.007, 95% CI: 0.001–0.033) should be treated with caution and are likely too high. This is because the low growth rate made it difficult to identify with confidence the multiple cohorts likely present in Wildflower Preserve. Tarpon spawn offshore along the west coast of Florida from May – July (Crabtree 1995) followed by a 2–4 week larval transport period into the estuary before they metamorphose into the juvenile stage (Shenker et al. 2002). Therefore, during this study we experienced two recruitment periods – one each in 2012 and 2013. Thus, the model contained multiple cohorts, each likely experiencing different survival rates, suggesting an overall lower survival rate for this habitat.

An important implication of the slow growth rate observed in this study is that juvenile tarpon that emigrated from the altered habitat provided by Wildflower Preserve were relatively small, making them more susceptible to predation. Although the difficulty differentiating cohorts and the slow growth rates made it difficult to estimate the age at which juvenile tarpon emigrate from this system, the slow growth meant that juvenile tarpon emigrated from Wildflower Preserve at a smaller size than tarpon in a nursery habitat with faster growth rates. For example, juvenile tarpon in Breder's (1944) study grew at a rate of 0.72 mm/day and would be approximately 263 mm long at age-1. Using this study's growth rates (0.07 mm/day), juvenile tarpon in Wildflower Preserve would be 25 mm long at age-1. This likely made them more susceptible to predation in the system or after emigration since larger size is an advantage for emigrants (Werner and Gilliam 1984) because larger individuals are less vulnerable to predation (Sogard 1997).

Wildflower Preserve suffered from multiple types of alteration. Most obvious was the physical alteration that changed the mixture of ponds and mangrove marsh into a series of semi-isolated ponds with a single connection to the estuary. More difficult to assess were the alteration of freshwater flows from the watershed and nutrient inputs. Changes in the timing, quantity, and quality of freshwater flows into estuarine habitats that results from coastal development and habitat alteration causes significant ecological impacts (Sklar and Browder 1998). For example, freshwater flow alterations affected juvenile snook diet in mangrove creeks, with implications for growth and survival (Adams et al. 2009). In this study, lower salinities were observed in all ponds during winter and early spring, which is the dry season, when natural systems would have higher salinity levels. Since osmotic regulation is an important factor in growth of estuarine fishes (Glover et al. 2013; Vargas-Chacoff et al. 2015), and tarpon are adapted to a wet-dry season dynamic, their growth may have suffered due to unnatural changes in salinity. Similarly, the ponds at Wildflower Preserve were once surrounded by a golf course and are now surrounded by residential development. Nutrient runoff from these watershed alterations can negatively impact nursery habitats (Hopkinson and Vallino 1995). For example, an increase in nitrogen, which is found in many lawn fertilizers, indirectly inhibits fish survival and growth through prey mortality by accumulating in primary producers and invertebrates (Camargo and Alonso 2006).

The concerns raised by the findings from Wildflower Preserve were twofold. First, compared to limited available data on juvenile tarpon growth, habitat alteration may be especially deleterious to juvenile tarpon survival. Second, if habitat alteration was universally negative for juvenile tarpon, the amount of habitat alteration in Florida posed a significant threat to the tarpon population and associated fishery, but at present we have no estimate of this impact. Since Wildflower Preserve reflects common characteristics of habitat alteration, (e.g., physical habitat changes, altered freshwater flows, high nutrient runoff), it was necessary to prioritize identification and characterization of juvenile tarpon habitats throughout Florida to inform conservation. The most effective approach to this challenge was to use citizen science.

Nursery habitat identification and characterization pose a challenge to effective fish conservation, in large part due to limited resources. Detailed studies of metrics

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used to evaluate nursery habitat quality (Beck et al. 2001) aren't possible unless these studies can be put in the context of nursery habitat availability and quality. In other words, to what extent are the findings from Wildflower Preserve applicable to altered habitats, what is the spatial extent of all available juvenile tarpon habitats, and what is the condition of those habitats on the natural-altered continuum? And of high importance – what tools are available to provide a relatively rapid yet useful assessment of the juvenile tarpon habitat universe in Florida?

We used the basic characteristic of physical alteration to categorize habitats as natural or altered. This metric required no training, (which was a benefit since Delaney et al. (2008) found that extended monitoring was unsustainable with the inclusion of a training component), was a universally recognized characteristic of anthropogenic changes to habitat, and could be assessed easily and directly by participants. We already faced the challenge of asking recreational anglers to share their fishing locations (these locations are generally highly protected), and sharing this information comes only with an elevated level of trust for economic and competitive reasons (Black et al. 2015). Indeed, this relationship between Bonefish & Tarpon Trust and the recreational fishing community had been fostered for well over a decade. Therefore, our goal was to obtain first-level estimates of habitat condition as unobtrusively as possible. This approach allowed us to create the first map of juvenile tarpon habitat locations in Florida. Treated as a living document, the map will be updated as additional reports are provided, and used as a foundation for more detailed studies in the future.

As demonstrated in this study, citizen science can be a powerful tool to address this challenge by providing new data on juvenile tarpon habitat locations as well as a first-level categorization of habitat condition. These foundational data are essential to increasing our knowledge of the extent and status of juvenile tarpon habitats. There is extensive research on the use of anglers to report catch data (Connelly and Brown 1995) and NOAA's Marine Recreational Information Program (MRIP) relies solely on angler reporting to manage, assess and maintain fish stocks (NOAA 2018). Therefore, using anglers as citizen scientists is a long-term proven mechanism for providing reliable information. Citizen scientists have also been used by local, state and federal agencies to aid in ecological studies (Silvertown 2009). A study by Danielsen et al. (2014) underscored the validity of citizen science when comparing monitoring data from community members to data collected by trained scientists and found high data correlation. Ultimately, using anglers is a more efficient and cost-effective method of obtaining basic habitat assessments that can be further assessed scientifically if necessary.

The use of citizen science in resource management is limited only by the information collected. Delaney et al. (2008) used elementary and middle school students to identify the range expansion of invasive crabs in the northeastern United States, which led to management recommendations to eradicate the non-native species. As technology advances, so do the capabilities of angler reporting through social media and cellular phone apps (Newman et al. 2012). As the use of citizen science progresses in the marine resource sector, datasets become more robust and easier to access for resource manager.

The research described in this manuscript is part of a larger, ongoing project to examine new approaches to provide data applicable to conservation and management in the context of perpetually data poor situations. For example, in Florida, habitat is not included in management of marine fisheries. In part this is due to governmental agency restrictions, and in part due to lack of appropriate data. This is especially concerning given the historical and ongoing loss and degradation of coastal marshes and mangroves, which contributed to the IUCN designation of tarpon as Vulnerable (Adams et al. 2013), as a concern for many fish species. Indeed, common snook (*Centropomus undecimalis*) supports an important recreational fishery in Florida, and is very tightly regulated. This regulation regime has resulted in a long-term upward trend in spawning biomass. However, the long-term trend in recruitment is one of decline (Muller et al. 2015), due in part to juvenile habitat loss. As are juvenile tarpon, juvenile snook are obligate users of mangrove and marsh habitats (Adams and Murchie 2015). Moreover, tarpon and other coastal species (e.g., bonefish, *Albula vulpes* and permit, *Trachinotus falcatus*) that rely on the coastal habitat mosaic lack formal stock assessments, necessitating a different approach to management and conservation. A mixed-methods approach, exemplified here by using habitat evaluation metrics, citizen science, and mapping, is essential to addressing conservation challenges for such fisheries (Adams et al. 2018). Future work in this program will: replicate the Wildflower Preserve study in sites identified by citizen scientists to evaluate habitats

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as categorized in this study (altered vs natural); expand the citizen science approach to identify more habitats; use the information provided by this study to inform a GIS-based approach to determine if remote mapping can replicate citizen science results; use the data from this study in an actionable knowledge framework (Adams 2017) to incorporate habitat into fisheries management of tarpon.

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