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How has the quality of bonefishing changed over the past 40 years? Using local ecological knowledge to quantitatively inform population declines in the South Florida flats fishery

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Abstract Local ecological knowledge (LEK) can be a valuable approach to fill in knowledge gaps in data-limited systems. Recent research has aimed to make LEK more quantitative-a key step to better integration of LEK into fisheries science and management. Here, we used LEK to a) quantify changes in bonefishing quality over time in South Florida as perceived by members of the flats fishery, and b) demonstrate the applicability of a life history calendar approach to LEK quantitative data collection. In an online survey, we asked anglers and guides to quantitatively evaluate changes in the quality of bonefishing, as a function of bonefish number and size, over the past 40 years in Biscayne Bay, Florida Bay, and the Florida Keys. Results showed a perceived 56% decrease in bonefish number, and a 45% decline in bonefish size since 1975. Respondents reported a decline in bonefish numbers that preceded the decline in size, with numbers starting to decline over 1985–1995, and size by 2005. In terms of the pattern of decline, bonefish number showed a heterogeneous pattern, with a slower rate of decline in 1985–2005 and an accelerated rate over 2005–2010, whereas the size decline was homogenous over 2000–2015. Overall, the study provides additional resolution, spatial coverage, and support to the pattern of bonefish population decline in the region, illustrating the utility of quantitative approaches to LEK data collection, and highlighting the value of integrating multiple knowledge sources to fully characterize ecological patterns.

Keywords Recreational fisheries · Local ecological knowledge · Bonefish · South Florida · Time series · Life history calendar

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Introduction

Local ecological knowledge (LEK) is a valuable tool to fill in knowledge gaps when other data sources are absent or limited. LEK consists of the knowledge, practices, and beliefs regarding ecological relationships that are gained through a mixture of observations and practical experience that are often placed-based, adapted over time, and shared among local resource users (Gilchrist et al. 2005; Anadon et al. 2009). In fisheries, LEK or fisher's knowledge has not been fully integrated into mainstream fisheries science and management, but its value is increasingly being recognized, by complementing or challenging traditional research practices (Bohensky et al. 2013; Hind 2015). For instance, LEK has been used to inform the dynamics of commercial and artisanal fisheries and relevant ecological processes (e.g., habitat use, spawning and migration) that can be applied to inform stock assessment, ecosystem-based management, and marine protected area design (Johannes et al. 2000; Johannes and Neis 2007; Hind 2015). In recent years, efforts have been made to elicit fisher's quantitative knowledge, along or in lieu of the more commonly-targeted qualitative knowledge and socioeconomic practices (Tesfamichael et al. 2014; Beaudreau and Levin 2014; Hind 2015). This quantitative knowledge has allowed for the reconstruction of historical trends, shown to be in agreement with those documented by biological datasets, which increases ones' confidence in the focal temporal patterns under study, and in the reliability of LEK-derived datasets (e.g., Beaudreau and Levin 2014).

While most LEK studies have focused on artisanal and commercial fisheries, only a small number of studies apply LEK to recreational fisheries. A recent review by Hind (2015) found recreational angler knowledge to be applied in only two studies (Zukowski et al. 2011; Beaudreau and Levin 2014). This is surprising given a high level of ecological awareness among anglers, and a growing desire to engage the recreational fishing community in conservation (Danylchuk and Cooke 2011; Adams and Murchie 2015). Yet, recreational fisheries can be data-limited due to the lack of landing records, particularly in the case of catch-and-release fisheries (Adams et al. 2014), and thus may benefit from LEK. Importantly over the last decade, there has been a recognition that recreational fisheries, not unlike commercial and sustenance fisheries, can be subject to stock depletion due to harvest (or fishing mortality), and to the interactive effects of environmental factors and exploitation (Planque et al. 2010; Post 2013), and thus the need to assess their long-term dynamics in catch and effort.

A good example of a data-limited recreational fisheries is the Caribbean recreational *flats fishery*. The fishery relies on shallow coastal tropical and subtropical habitat mosaics, and is comprised of Atlantic tarpon (*Megalops atlanticus*), permit (*Trachinotus falcatus*), common snook (*Centropomus undecimalis*), and bonefish (*Albula vulpes) (*Adams and Cooke 2015). These species support valuable socioeconomic fisheries both locally and regionally (Fedler 2013), and are increasing in popularity as a key component of ecotourism and conservation efforts (e.g., Zwirn et al. 2005), but data on the status and trends of the stocks are lacking (Adams 2017).

In South Florida, the flats fishery is largely catch-and-release, but despite this, the fishery appears to be suffering concerning declines. In particular, there is increasing evidence of a decline in bonefish over recent decades (Sosin 2008; Larkin et al. 2010; Frezza and Clem 2015; Santos et al. 2017). Fishing guides surveyed in the Florida Keys reported a decline in catches- 50% decline reported by Larkin et al. (2010), and 68% decline by Frezza and Clem (2015). Declines were also reported in two fisheries dependent datasets (FDD), tournament catches in Islamorada Keys (Larkin 2011), and guide reports from Florida Bay (Santos et al. 2017). Yet these reports lack temporal resolution on the pattern of decline (e.g., gradual vs. punctuated) that can help us build timeseries to which relate drivers, and a comprehensive spatial coverage throughout all bonefishing grounds in the region. Thus in this study, we used LEK to a) quantify changes in bonefishing quality throughout South Florida (USA) over time as perceived by bonefishers, and thus provide additional resolution, spatial coverage, and support to the pattern of bonefish population decline being observed in the region, and b) demonstrate a quantitative approach to LEK. We applied a demographic social science approach, using a life history calendar (LHC; Freedman et al. 1988) to improve LEK data collection. We used an online survey of anglers and guides to quantify their perception of changes in the quality of the fishery between 1975 and 2015, in terms of two focal metrics, bonefish number and size.

Methods

Study domain

The spatial domain of the survey encompassed all of the recreational bonefishing areas in South Florida, extending approximately 400 km from Biscayne Bay to the Marquesas (Fig. 1). The area is particularly vulnerable to adverse changes resulting from an ever-increasing human population, coastal development, and associated ecosystem degradation and fishing exploitation (Ault et al. 2005). We focused on three main regions in the

(a)

(b) How would you rate your bonefishing experience in terms of the number of bonefish you caught across years and regions on a scale from 1-5?

5	4	3	2	1
Very Good	Good	Fair	Poor	Very Poor

	Today (2014/2015)	5 years ago	10 years ago	15 years ago
Region 1: Biscayne Bay	☐	☐	☐	☐
Region 2a: NW FL Bay	☐	☐	☐	☐
Region 2b: NE FL Bay	☐	☐	☐	☐
Region 2c: SW FL Bay	☐	☐	☐	☐
Region 2d: SE FL Bay	☐	☐	☐	☐
Region 3: Upper Keys	☐	☐	☐	☐
Region 4: Middle Keys	☐	☐	☐	☐
Region 5: Lower Keys	☐	☐	☐	☐

Fig. 1 **a** Map of the study area showing the focal regions targeted in the angler survey: Biscayne Bay, Florida Bay (shown as 4 subregions that were combined), and the Florida Keys, combined for analyses across the Upper, Middle and Lower Keys, and **b** example of the LHC matrix question about bonefish number across REGIONS and subregions, and four time PERIODS

South Florida bonefish fishery: Biscayne Bay, Florida Bay and the Florida Keys (Fig. 1a). Biscayne Bay is a shallow-water subtropical lagoon located adjacent to the city of Miami, with more than half of the bay contained within Biscayne National Park. Our study focused on the central and southern part of the bay (Virginia Key to

Barnes Sound), known to be the core of bonefish habitat (Larkin 2011). Florida Bay is the largest estuary in Florida, and 80% of it is contained within Everglades National Park. The bay consists of a patchwork of interconnected basins, shallow mud banks, seagrasses, mangrove islands, and tidal channels. The Florida Keys consist of a chain of islands, surrounded by extensive seagrass meadows and reef areas that are part of the Florida Keys National Marine Sanctuary and strongly dependent on tourism and associated activities, such as recreational fisheries (Cook and Heinen 2005; Fedler 2013). For the purposes of the survey, we delineated this last region into three subregions: Upper Florida Keys (Key Largo to Lower Matecumbe Key), Middle Keys (Long Key to the Seven Mile Bridge), and Lower Keys (Seven Mile Bridge to the Marquesas). As elsewhere, areas on the bayside of the Upper and northern part of the Middle Keys were considered part of Florida Bay (Frezza and Clem 2015).

Online survey

In order to quantify perceived changes in the recreational bonefish fishery, we designed a semi-structured, targeted survey (Huntington 2000), that was administered via the online platform Qualtrics (Qualtrics©, Provo, UT). The survey relied on a nonrandom, targeted snowball sampling approach (e.g., Dusek et al. 2015), whereby survey participants shared the survey invitation with other appropriate subjects for study, and thus fulfilled the qualifications of the target population (i.e., fished for bonefish in South Florida). The survey targeted anglers and guides that had fished or presently fished the Florida Keys, Florida Bay, and/or Biscayne Bay for bonefish. Survey distribution focused on three main approaches: 1) emails to fishing groups and fishing guide associations for subsequent distribution to their members via various platforms (i.e., emails to member listserv, websites and social media), 2) articles on fishing magazines (via print, websites and social media), and 3) advertisements at fishing stores in Miami and the Florida Keys (i.e., a display with business cards providing information and a link to the online survey). This snowballing sampling with various survey distribution approaches may counter sampling bias (Drescher et al. 2013). Sampling bias occurs when survey respondents are not representative of the entire population, but initiating the snowballing process at independent starting points may allow for the survey to tap into multiple networks of respondents.

The survey had a total of 10 questions, with the core of the survey being the LHC middle section where respondents were asked to evaluate or score the quality of bonefishing for the spatiotemporal domain they fished. The first part of the survey asked respondents demographic questions about their age, gender and place of residency, years of bonefishing experience and frequency, whether they guided and frequency and duration of guiding activities, and whether a member of a fishing organization. The survey ended with three open-ended questions that asked the respondents ‘Do you think that bonefishing has changed over the time you fished in South Florida? If yes, describe how bonefishing has changed? And, what do you think is driving these changes in bonefishing in South Florida?’ The survey was opened online from August 2015 to January 2016.

Analyses presented here focus on the core retrospective information obtained in the LHC middle section of the survey. A LHC approach allows for the collection of reliable and detailed retrospective data, focusing on the timing and sequence of life events (Freedman et al. 1988; Axinn et al. 1999). By using a matrix of time periods (horizontal) and events (vertical), the approach visually cues the survey respondent, enhancing autobiographical recall, and accuracy in the timing of events (Belli et al. 2001; Glasner et al. 2015; Morselli et al. 2016). We adapted the LHC methodology by providing survey respondents with a matrix of temporal events across spatial domains (Fig. 1b). For time, respondents were asked to evaluate the quality of bonefishing at present, and 5, 10, 15, 20, 30 and 40 years ago, corresponding to seven focal time steps or PERIODS: 2015, 2010, 2005, 2000, 1995, 1985 and 1975. Time PERIODS were selected to be simple in order to encourage recall, and precision in the sequence of related events (Freedman et al. 1988). PERIODS went as far back as 1975, because beyond 1975, sample sizes were too small with too few anglers fishing beyond 40 years. For the spatial domain of the survey, we included five focal REGIONS: Biscayne Bay, Florida Bay, Uppers Keys, Middle Keys, and Lower Keys. Respondents were asked to only evaluate bonefishing over their own personal fishing history and spatial domain. For example, an angler that fished for the past 20 years (2015–1995) in Florida Bay and the Upper Keys was expected to evaluate the quality of bonefishing across the five time steps encompassing his/her fishing history and two regions, totaling 10 entries in the bonefish number matrix, and 10 entries in the bonefish size matrix.

Using this format, respondents were asked to score the quality of bonefishing in terms of two metrics: the number of bonefish and the size of bonefish in the two separate matrices. Each matrix used a five-point Likert scale (one for the lowest quality and five for the highest quality, Fig. 1b). The two matrices were accompanied by reference points for what to consider high vs. low quality in terms of both number and size. These reference points provided common metrics to minimize bias in the scoring of fishing quality, and were developed in consultation with a subset of experienced South Florida anglers and guides. They were also South Florida specific, since for instance, bonefish in this region are typically larger than elsewhere in the Caribbean basin (Larkin 2011). For bonefish number, fishers were asked to score the number of shots at bonefish (i.e., how many times an angler had an opportunity to cast at bonefish) using the following scale: 1 = 0 shots, 2 = 1–3 shots, 3 = 4–10 shots, 4 ≥ 10 shots, 5 = unlimited shots. Since bonefishing is most often done by sight fishing (i.e., visual confirmation before casting; Fernandez and Adams 2004), number of shots was used as a proxy for bonefish numbers encountered by anglers (and hereafter referred to as bonefish numbers). For bonefish size, fishers were asked to rate quality as follows: 1 < 2 lbs., 2 = 2–5 lbs., 3 = 6–8 lbs., 4 = 8–10 lbs., 5 > 10 lbs.

A total of 219 respondents completed the survey and provided scores of bonefishing quality in the PERIODS by REGIONS matrices for both bonefish size and numbers. Because survey respondents were asked to score bonefishing quality only for the time periods for which they have knowledge on, sample sizes varied across PERIODS. Final samples sizes used in analyses were as follows: 33 scores for 1975, 66 for 1985, 117 for 1995, 159 for 2000, 176 for 2005, 175 for 2010, and 184 scores for 2015.

Statistical analyses

We used linear regression spline models to assess the temporal trends in bonefish size and number, and detect the presence/absence of heterogeneity among the seven time PERIODS between 1975 and 2015. For both quality measures (size and number), we first contrasted models with and without angler traits to assess the effectiveness of our LEK data collection via LHC, and the strength of potential sources of bias in perception (e.g., shifting baselines, Beaudreau and Levin 2014). The angler traits included in the models were EXPERIENCE and ANGLER TYPE. EXPERIENCE consisted of four levels based on years bonefishing: level 1 ≤ 5 years, level 2 = 5–15 years, level 3 = 15–30 years, and level 4 > 30 years). ANGLER TYPE consisted of contrasting the perception between professional fishing guides and recreational anglers. Along with these angler variables, models included time PERIOD as a continuous variable to allow for the sequential comparison of the seven focal time steps (1975–1985, 1985–1995, 1995–2000, 2000–2005, 2005–2010, and 2010–2015), and fishing REGION as a categorical variable to allow for examining spatial variation (Biscayne Bay, Florida Bay vs. the Florida Keys subregions combined, Fig. 1). Models with and without the angler traits were compared using an ANOVA F statistic to detect improvement between the models' residuals sums of square.

Once a model was selected, linear spline models were parameterized as a marginal test to detect changes in slope from the preceding time step (i.e., the presence of temporal heterogeneity). Here, the consecutive model coefficients correspond to the change in slope as compared to the previous time step. The relative importance of the four explanatory variables in the linear models (PERIOD, REGION, EXPERIENCE and ANGLER TYPE) was then quantified using the Lindeman, Merenda and Gold (LMG) simple unweighted averages (Grömping 2006). This metric of relative importance is based on sequential R^2s, and controls for variable-ordering dependence using unweighted averaging. Last, Tukey post hoc tests were performed to assess pairwise differences among the levels of the three categorical variables in the models (REGION, EXPERIENCE and ANGLER TYPE). All statistical analyses were performed in R v3.2.5 (R Core Team). The linear spline models, the variables relative importance metric, and Tukey post hoc test were performed with the lspline (Bojanowski 2017), relaimpo (Grömping 2006), and multcomp (Hothorn et al. 2008) R packages respectively.

Results

Of the 219 respondents completing the survey, 180 identified themselves as anglers (82%), and 39 as fishing guides (18%). Respondents were composed of varing levels of fishing EXPERIENCE, with 11% of respondents having expertise level 1 (≤5 years), 21% with level 2 (5–15 years), 33% with level 3 (15–30 years), and 17% with level 4 (>30 years). Respondents varied in age: 15% were < 35 years old, 37% were between 35 and 54 years old, and 48% were > 55 years old, with 4% women and 96% male respondents, and 62% being members of a fishing organization or group. In terms of fishing frequency, respondents reported an average of 26 days of bonefish per year (range was 1 to 200 days). Last, 20% of respondents were full-time residents of South Florida, 20% were part-time residents, and 60% were nonresident anglers.

Overall, respondents perceived a decline in bonefishing quality in South Florida over the past 40 years. Declines in both metrics of quality, bonefish size and numbers, were reported. The decline in the number of bonefish was perceived to be greater and earlier in time than the decline in fish size (Fig. 2). Respondents perceived about a 56% decrease in bonefish number, scoring on average a 4.5 out of 5 in 1975, relative to an average of 2.0 in 2015, and a 45% decrease in bonefish size over the 40 years evaluated by respondents (4.0 in 1975 relative to 2.2 in 2015).

For both size and number, the linear spline models that included EXPERIENCE level and ANGLE TYPE showed a small but significant model improvement (i.e., reduction in the residual sum of squares) in comparison with the models without these angler traits (Online Resource 1), thus we considered these models in subsequent analyses. These final models were both significant and explained 32% and 25% of the variance in the bonefish number and size scores respectively (Table 1). All terms included in the models (i.e., PERIOD, EXPERIENCE, ANGLER TYPE, and REGION) were significant, with the exception of EXPERIENCE in the size model. These linear spline models showed distinct temporal patterns in how anglers and guides perceived changes in the size and number of bonefish in the fishery, which are described separately below.

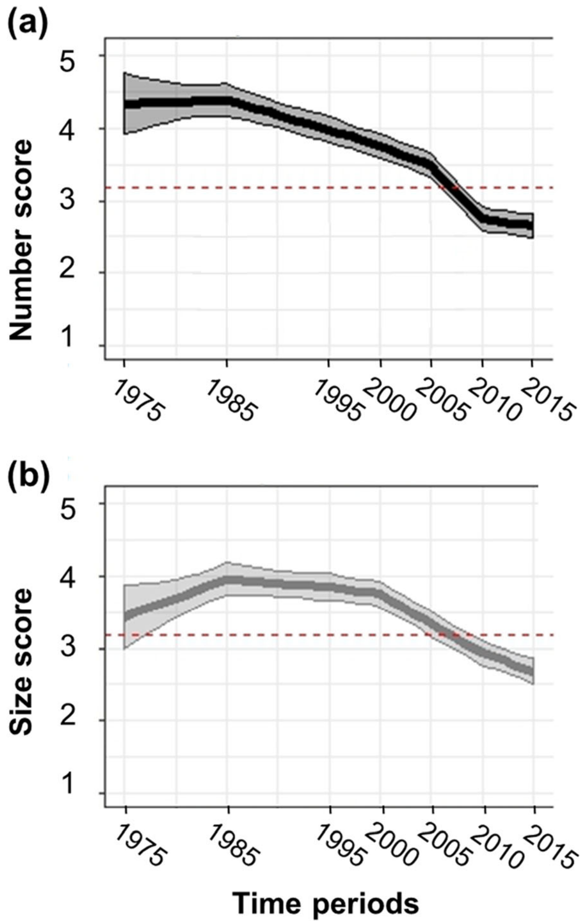

Fig. 2 Mean fitted scores from the online survey for **a** bonefish numbers and **b** size across the seven time PERIODS between 1975 and 2015. Shading shows 95% confidence levels and dotted horizontal lines show global means

Temporal variation in bonefish numbers

Respondents perceived a decline in bonefish numbers, as told by the number of shots at catching a bonefish, starting in 1985 (Figs. 2a, 3a). Four of the six time period comparisons in the linear spline model had a significant negative coefficient, suggesting a long-term declining trend, particularly in the middle of the time series 1985–2010 (Table 2a). The rate of decline over this period was consistent between 1985 and 2005 (i.e., no difference among slopes), but there was an acceleration of the decline between 2005 and 2010 (Table 3a). Scores for bonefish number declined by 8.3% between 2000 and 2005, but by 22.0% for the period 2005–2010 (Fig. 2a).

This temporal trend in bonefish numbers was consistent across the three fishing REGIONS, among levels of fishing EXPERIENCE, and as a function of ANGLER TYPE with some small differences (Fig. 3a, Table 2a). Importantly, the relative importance of these regressors in the spline model was minimal relative to the overwhelming effect of the temporal factor. PERIOD accounted for 92% of the variance in bonefish number, while the contributions of REGION, EXPERIENCE

Table 1 Adjusted R^2, associated F-statistics and estimated P values for the bonefish number and bonefish size linear spline models, along with model fit statistics for both models

Terms	df	Sum.sq	Mean.sq	F	P value
Linear Spline Model: **Number**					
Period	6	473	78.8	102.9	0.001
Experience	3	9.1	3.1	4	0.01
Angler type	1	4	4	5.2	0.02
Region	2	38.5	19.2	25.1	0.001
Residuals	1438	1101.4	0.8		
Linear Spline Model: Size					
Period	6	303.8	50.6	62.3	0.001
Experience	3	5.1	1.7	2.2	0.1
Angler type	1	6.7	6.7	8.2	0.001
Region	2	79.3	39.7	48.9	0.001
Residuals	1438	1167.8	0.8		
Models Coefficients of Determination	R_{adj}^2	$F_{12,1438}$	P value		
Number	0.32	57.1	0.001		
Size	0.25	40.5	0.001		

and ANGLER TYPE summed up to only 8% (Fig. 4a). Across regions, bonefish number scores were higher in Biscayne Bay relative to both Florida Bay and the Florida Keys (Fig. 4b, Online Resource 2). As a function of EXPERIENCE level, only novice respondents differed, and they only differed from expertise level 2 (Fig. 4c, Table 2a, and Online Resource 2). Expertise level 1 respondents scored bonefish numbers higher than respondents with greater experience. Anglers and guides scored bonefish numbers similarly, with guide scores appearing more variable than those of anglers, possibly due to the lower sample size (Fig. 4d, Online Resource 2).

Temporal variation in bonefish size

Survey respondents perceived an increase in bonefish size from 1975 to 1985, but a decline at the last three time steps scored: 2000–2005, 2005–2010 and 2010–2015 (Table 2b, Fig. 2b). This decline over this last 15 years, 2000–2015, was homogeneous, with a similar slope across time steps (Table 3b). As seen with bonefish number, changes in bonefish size over time were largely consistent across the three fishing REGIONS, among levels of EXPERIENCE, and as a function of ANGLER TYPE (Fig. 3b).

Variation in the size scoring was largely influenced by PERIOD, secondarily by the space variables, but minimally by angler traits. More than 70% of the variation was due to the PERIOD effect, followed by REGION, which contributed 21% of the variation (Fig. 5a).

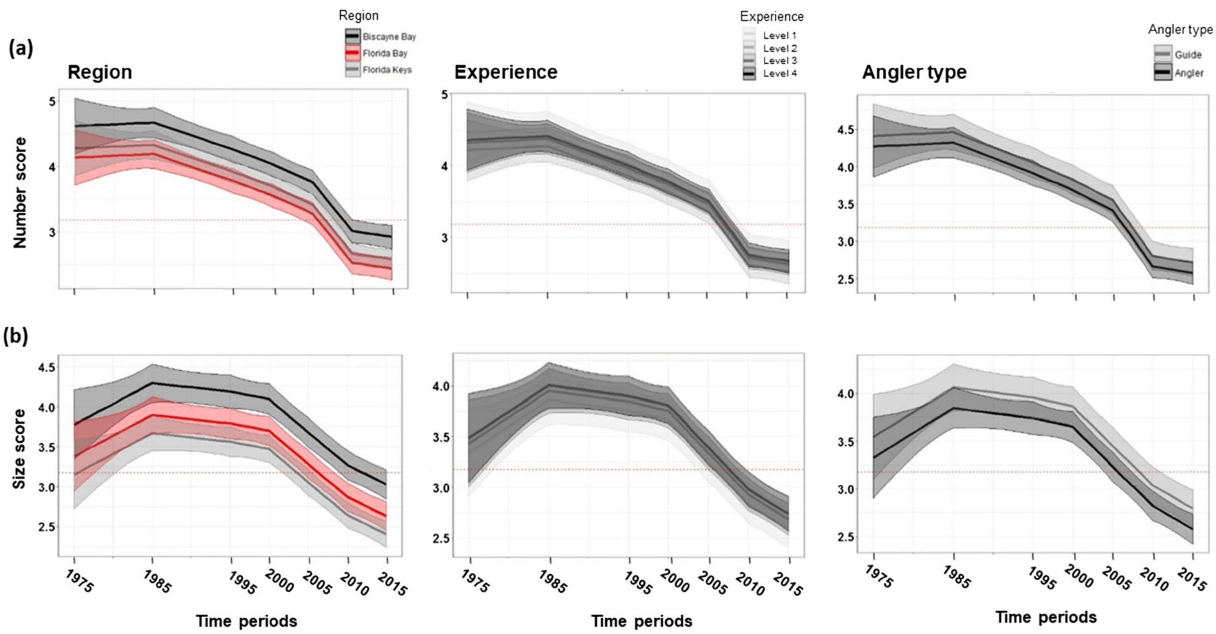

Fig. 3 Mean fitted scores for **a** bonefish number and **b** size as a function of fishing REGION, EXPERIENCE level, and ANGLER TYPE. Shading illustrate 95% confidence levels and dotted lines indicate global means

Table 2 List of coefficients (Coef) associated with each term included in the (**a**) bonefish number and (**b**) size linear spline models

Term	Coef.	SE	F	P value
Linear Spline Model: Number				
Intercept	−5.43	43.81	−0.12	0.90
1975–1985	0.01	0.02	0.23	0.81
1985–1995	**−0.04**	**0.01**	**−3.76**	**0.001**
1995–2000	**−0.05**	**0.02**	**−2.67**	**0.01**
2000–2005	**−0.05**	**0.02**	**−3.59**	**0.001**
2005–2010	**−0.15**	**0.01**	**−10.45**	**0.001**
2010–2015	−0.02	0.01	−1.23	0.22
Level 2	**−0.25**	**0.08**	**−3.22**	**0.00**
Level 3	**−0.14**	**0.07**	**−2.03**	**0.04**
Level 4	−0.11	0.08	−1.31	0.19
Angler type	**−0.14**	**0.07**	**−2.06**	**0.04**
Florida Bay	**−0.48**	**0.07**	**−7.00**	**0.001**
Florida Keys	**−0.34**	**0.06**	**−5.50**	**0.001**
(b) Linear Spline Model: Size				
Intercept	**−98.94**	**45.12**	**−2.19**	**0.03**
1975–1985	**0.05**	**0.02**	**2.29**	**0.02**
1985–1995	−0.01	0.01	−0.94	0.35
1995–2000	−0.02	0.02	−1.06	0.29
2000–2005	**−0.08**	**0.02**	**−5.36**	**0.001**
2005–2010	**−0.08**	**0.01**	**−5.57**	**0.001**
2010–2015	**−0.05**	**0.01**	**−3.31**	**0.001**
Level 2	0.13	0.08	1.68	0.09
Level 3	0.09	0.07	1.24	0.22
Level 4	0.15	0.08	1.77	0.08
Angler type	**−0.22**	**0.07**	**−3.03**	**0.001**
Florida Bay	**−0.40**	**0.07**	**−5.64**	**0.001**
Florida Keys	**−0.63**	**0.06**	**−9.81**	**0.001**

Shown are coefficients, standard errors (SE), *F* statistics, and P values for the null hypothesis of no difference with the reference point. Significant coefficients are bolded

Here, REGION played a stronger role in driving variation in the scoring of size relative to bonefish number, 21% vs. 6% (Figs. 4a, 5a). Anglers and guides scored significant size differences with larger bonefish in Biscayne Bay, intermediate in Florida Bay, and smaller in the Florida Keys (Fig. 5b, Online Resource 2). Together, EXPERIENCE and ANGLER TYPE explained less than 1% of the variance in bonefish size (Fig. 5a), and resulted in significantly different scoring only between anglers and guides. Fishing guides scored bonefish size significantly higher than anglers, but the difference was only 4% (Fig. 5d, Online Resource 2).

Table 3 Marginal effect tests used to detect variation in slopes in **a** bonefish number and **b** size among consecutive time PERIODS

Term	Coef	SE	F	*P* value
(a) Linear Spline Model: Number (Marginal Effects)				
Intercept	−6.48	38.16	−0.17	0.87
1975–1985	0.01	0.02	0.28	0.78
1985–1995	−0.04	0.02	−1.73	0.08
1995–2000	−0.01	0.02	−0.47	0.64
2000–2005	−0.01	0.03	−0.30	0.77
2005–2010	**−0.09**	**0.02**	**−4.01**	**0.001**
2010–2015	**0.13**	**0.02**	**5.58**	**0.001**
(b) Linear Spline Model: Size (Marginal Effects)				
Intercept	−50.65	41.23	−1.23	0.22
1975–1985	0.03	0.02	1.32	0.19
1985–1995	−0.03	0.03	−1.23	0.22
1995–2000	−0.02	0.02	−0.65	0.51
2000–2005	−0.05	0.03	−1.81	0.07
2005–2010	−0.01	0.02	−0.57	0.57
2010–2015	0.03	0.02	1.30	0.20

Shown are coefficients (Coef), standard errors (SE), *F*-statistics, and estimated P values. Significant coefficients are bolded

Discussion

Although translation of LEK to fisheries management remains limited, there is increasing evidence of the reliability and high quality of LEK-based datasets (Beaudreau and Levin 2014; Tesfamichael et al. 2014; Hind 2015; Sáenz-Arroyo and Revollo-Fernández 2016). In our study, we used LEK to quantify changes in bonefishing quality over time throughout South Florida as perceived by members of the flats fishery, and thus obtain additional evidence and spatiotemporal resolution on a reported pattern of decline for *A. vulpes* (Larkin 2011; Frezza and Clem 2015; Santos et al. 2017). We also illustrated the utility of an LHC approach for quantitative LEK data collection. Our online survey of anglers and guides revealed a perceived 56% decrease in bonefish number, and a 45% decline in bonefish size over the past 40 years. The decline in bonefish number (as told by respondents scoring shots at bonefish) preceded the decline in bonefish size, with numbers showing a decline between 1985 and 1995, whereas the decline in size was evident by 2005. The decline in size was homogenous

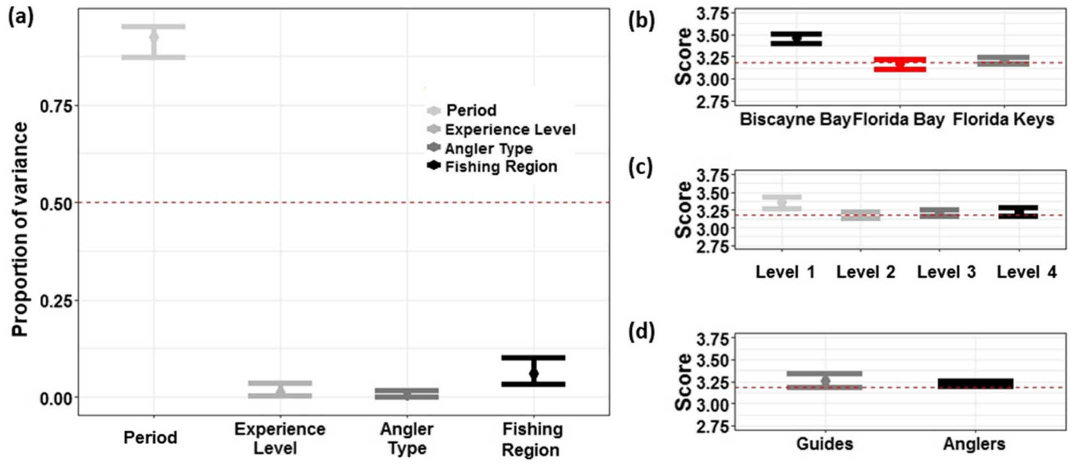

Fig. 4 **a** Contribution of explanatory variables (PERIOD, EXPERIENCE, ANGLER TYPE, REGION) to variation in bonefish number scores in the survey. Error bars illustrate 95% confidence levels estimated with a bootstrapping approach. Mean scores (±SE) for bonefish numbers are shown as a function of: **b** fishing REGIONS, **c** EXPERIENCE levels, and **d** ANGLER TYPE. Dotted lines indicate global means

over 2000–2015, but bonefish numbers showed a heterogeneous pattern with a lower rate of decline in 1985–2005, and an accelerated rate over 2005–2010. Over 2010–2015, fishers noted a decline in size, but no further decline in number, suggesting a potential slowing down of the downward trend.

Our statistical modeling showed that variation in the scoring of bonefishing quality, in terms of both number and size, was largely a function of the temporal axis PERIOD, and not the spatial regional comparison (but see Santos et al. 2018 for more detailed spatial patterns extracted from this and other datasets). Importantly, the effect of angler traits on the perception of bonefish change in quality was minimal. Both years of experience bonefishing and angler type (angler vs. fishing guide) explained only 1–2% of the variation in number and size scores, suggesting a low potential for respondent traits bias. This finding contradicts a common expectation that variation in how individuals 'sample' the environment (e.g., as an angler or guide) or the time frame of the sampling (e.g., frequency and duration) frame their 'information environment', driving differences in their perceptions of ecological patterns (Verweij et al. 2010).

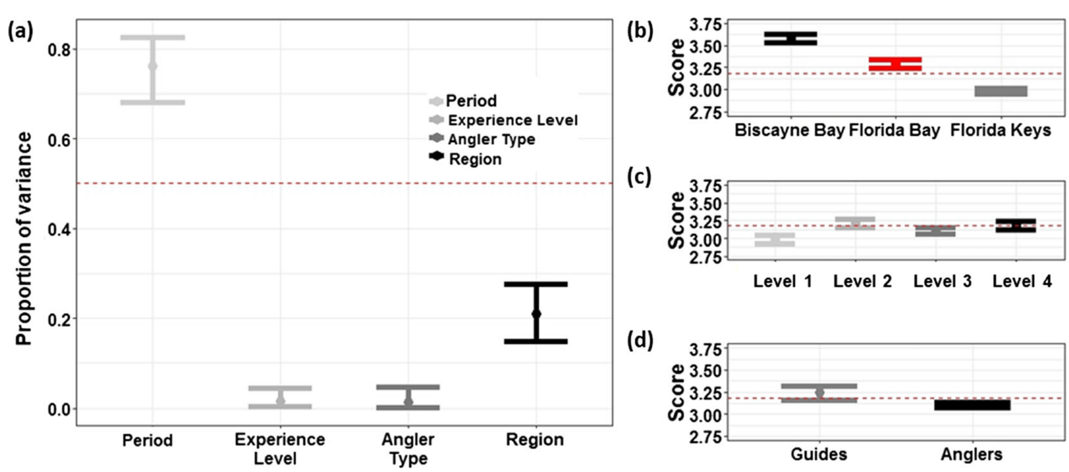

Fig. 5 **a** Contribution of explanatory variables (PERIOD, EXPERIENCE, ANGLER TYPE, REGION) to variation in bonefish size scores in the survey. Error bars illustrate 95% confidence levels estimated with a bootstrapping approach. Mean scores (±SE) for bonefish numbers are shown as a function of: **b** fishing REGIONS, **c** EXPERIENCE levels, and **d** ANGLER TYPE. Dotted lines indicate global means

Data obtained from surveys and interviews is filtered through the memory, experiences, and perceptions of respondents, which can cause heterogeneity and biases in respondent perceptions through a number of mechanisms (Daw 2010). For instance, we may expect older or more experienced respondents to perceive greater changes in abundance than less experienced anglers (Sáenz-Arroyo et al. 2006; Ainsworth et al. 2008; Beaudreau and Levin 2014). This variation in perception may result from *shifting baselines*, or the changing human perceptions about ecological systems due to a loss of experience with past conditions (generational amnesia) or to individuals updating their own perception (i.e., individual amnesia, Papworth et al. 2009). These changing perceptions can lead to the acceptance of degraded conditions as the new baseline, hindering conservation efforts, particularly in what concerns target setting for ecosystem state and species regeneration (Pauly 1995; Papworth et al. 2009). In our study, and similar to a previous LEK study on bonefish (Frezza and Clem 2015), we found no evidence of a relationship between experience and perceived changes in abundance, suggesting a lack of generational amnesia. This is often attributed to high levels of both information on past conditions, and information sharing among resource users (Papworth et al. 2009), possibly operating in the South Florida flats fishery.

We hypothesize that the LHC approach used in data collection may contribute to minimize biases in the perception of ecological change particularly related to memory. Deviations between ecological change and perceptions of such change by resource users may result from individual amnesia, where users update their perception of normality, and although they may have experienced different conditions in the past, they believe present conditions are the same as past conditions (Papworth et al. 2009; Daw 2010). The LHC should counteract these effects by incorporating cognitive psychology-supported techniques aimed at improving autobiographical memory during retrospective surveys (Freedman et al. 1988).

The LHC approach was developed in the social sciences and medicine in the context of longitudinal research, and has been shown to be an effective tool that increases the quality and reliability of nuanced retrospective data obtained from surveyed and interviewed respondents (Axinn et al. 1999; Belli et al. 2001; Glasner et al. 2015; Morselli et al. 2016). LHC uses visual aids, inquires about streams of events, records event sequences, and contextualizes questions about various life events (in our case, fishing experiences over space) in order to reduce response error and improve recall. In particular, the visual nature of a LHC (e.g., Fig. 1b) encourages sequencing and parallel retrieval of temporal information, and allows respondents to evaluate whether they have correctly reported the coincidence or ordering of various events, leading to a more accurate timing of events.

We propose that an LHC approach may contribute to higher data quality and a more quantitative approach to LEK. In his review of the application of LEK in fisheries, Hind (2015) points to the value of recent efforts to make LEK more quantitative (i.e., Tesfamichael et al. 2014) that are needed to promote fuller incorporation of LEK into fisheries management and conservation. By optimizing retrospective recall and allowing for detailed data on multiple life events in a structured format, the LHC could improve LEK data collection. Last, we expect the use of reference points for evaluating changes in resources state may be another improvement to LEK data collection, particularly addressing the issue of variance when considering user responses (i.e., Beaudreau and Levin 2014). Reference points may allow for a larger degree of fuzziness compartmentalization, and for framing of angler's qualitative perceptions into a format that is more easily quantified and compared (e.g., Ainsworth et al. 2008).

Our study follows on previous work on South Florida bonefish, and provides additional evidence and resolution on a spatiotemporal pattern of decline for South Florida bonefish. By combining multiple lines of inference (i.e., FDD with LEK survey and interview data, Table 4), we can gain confidence on patterns, and strengthen inference when fisheries-independent data are lacking (e.g., Santos et al. 2018). In our study, we found about a 50% decline in bonefish quality that starts in 1985–1995, and accelerated in 2005–2010. This accelerated rate matched the marked decline observed in FDD (for Florida Bay) across multiple fisheries, including bonefish, as a function of the extreme 2010 cold spell (Boucek and Rehage 2014; Santos et al. 2016; Santos et al. 2017), which was also noted by the most experienced bonefish anglers and guides in key informant interviews (Kroloff et al. 2018).

In terms of the magnitude of South Florida bonefish decline, the 56% decline in the quality of bonefishing number agrees with previous FDD (Table 4). Santos et al. (2017), in an analysis of fishing guide reports concluded a 42% decline in bonefish catch per unit effort (CPUE) for Florida Bay, while Larkin (2011) described a 47% decline in tournament CPUE for

Table 4 Summary of studies, including present study, reporting on the temporal dynamics of bonefish in South Florida and describing a decline

Source*	Dataset type	Sample size	Spatial coverage	Temporal coverage	Temporal attributes of bonefish decline reported		
					Magnitude	Timing	Pattern
Larkin et al. 2010	Mail survey of guides	190 respondents	Florida Keys	2002	50% of guides report a decline	Decline reported for 1991–2001	Not reported
Larkin 2011	CPUE from tournament catches	1861 catch records	Florida Keys	1968–2010	47% decline in CPUE	Decline reported for 1997–2010	Largest decline in 1997–1998, slower rate post-1998
Frezza and Clem 2015	Targeted paper survey of most experienced anglers & guides	64 respondents (84% guides)	Biscayne Bay, Florida Bay & Florida Keys	Years fishing (12–64 yrs)	Average decline reported is 78% over years fishing & 49% report a decline in size	91% report the greatest decline in 2001–2011	48% reported decline as steady
Santos et al. 2017	Bonefish CPUE from guide reports	5039 reports	Florida Bay	1980–2014	42% decline in CPUE	Breakpoint in timeseries in 1999	Monotonic decline between 1988 and 2006, lowest CPUE post-2010
Kroloff et al. 2018	Key informant interviews	20 interviews with most experienced angles and guides	Biscayne Bay, Florida Bay & Florida Keys	1956–2015	One respondent describe a change from 85% to 5% of guiding targeting bonefish	40% report decline in 1990s-2004,35-% in 2005–2010	50% of respondents describe a gradual decline
This study	Online survey of anglers & guides (18% guides)	219 respondents	Biscayne Bay, Florida Bay & Florida Keys	1975–2015	56% decline in numbers & 45% decline in size	Decline in numbers between 1985 and 2010 & in size between 2000 and 2015	For numbers, similar rate of decline for 1985–2005 & accelerated rate in 2005–2010. Steady decline for size

*Santos et al. (2018) also examines this decline, but the focus is spatial and thus not included here

Islamorada. In contrast, a larger 78% decline was reported by a targeted survey of experienced guides and anglers across South Florida (Frezza and Clem 2015). In terms of timing, our 1985–1995 start of a decline agrees with Santos et al. (2017)'s and Larkin et al. (2010)'s reported timing, but contrasts Larkin's (2011) and Frezza and Clem's (2015) findings of later declines in the late 1990s into 2010 (Table 4). In detailed interviews with key informants (with an average of 42 years of bonefishing), Kroloff et al. (2018) reported that 40% of respondents identified the decline to begin in the 1990s, while 35% perceived a start in the late 2000s.

Key among these comparisons is the concordance of LEK data with other independent data sources, such as FDD. In particular, we find that our data are congruent with the guide records reported for Florida Bay (Santos et al. 2017), providing some confidence in the interpretation that the perceived changes in bonefishing quality are telling of population declines. No fisheries-independent efforts tracking population size are available for bonefish. The timing (starting in late 1980s), magnitude (approximately 50%), and pattern of decline (linear with minimal values and acceleration post-2010 cold event) in our survey match this FDD, albeit this dataset only covers one of the three regions tested in our study. Studies that show consistency across these datasets are critical to establishing the reliability and quality of LEK-based efforts and to providing needed confidence in ecological patterns. Among others, consistencies between biological and LEK datasets have been shown for historical records of marine species abundance in Puget Sound (Beaudreau and Levin 2014), population trends in terrestrial tortoises in Spain (Anadon et al. 2009), the abalone fishery in Baja California (Sáenz-Arroyo and Revollo-Fernández 2016), and lake hydrodynamics in the Alps (Laborde et al. 2012). Studies have even shown the superiority of LEK relative to other data sources. Aylesworth et al. (2017) showed fisher knowledge provided more information on rare and depleted fish species at larger spatial scales, with less effort and cost than citizen science, scientific diving surveys, and government research trawls.

In sum, our study provides additional resolution and confidence on the long-term trend of decline in the bonefish recreational fishery in South Florida. Time series of abundance are the most basic information needed in natural resource assessment (Caddy and Gulland 1983), yet are often difficult to obtain in recreational fisheries, constraining our ability to assess their sustainability and drivers of temporal patterns. In a broader scope, this study advances the use of quantitative approaches to improving LEK, and contributes to increasing evidence on the value of integrating multiple knowledge sources to characterize ecological patterns. From a conservation perspective, gaining a full understanding of the spatiotemporal pattern of a declining population is the first step to detecting, diagnosing and halting a population decline (i.e., *declining population paradigm*, Caughley 1994), and for the robust hypothesis testing needed to identify causes of decline (Wolf and Mangel 2008). For South Florida bonefish, making sense of the spatial extent and magnitude of decline (see also Santos et al. 2018, and Brownscombe et al. 2018) is a fundamental step to ongoing and forthcoming efforts to identify drivers and develop successful conservation, restoration and management measures.

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Compliance with ethical standards

Ethical statement Our survey was approved by the Human Subjects Board at Florida International University and was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. For this type of study formal consent is not required.

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