Environ Biol Fish
https://doi.org/10.1007/s10641-022-01314-9

Temporal trends of Biscayne Bay pink shrimp fisheries catch, economic indicators, and potential interactions with South Florida recreational flats fisheries

Ryan J. Rezek · W. Ryan James · Valentina Bautista · Ian Zink · Jennifer S. Rehage · Rolando O. Santos

Received: 1 February 2022 / Accepted: 25 July 2022

Abstract Pink shrimp (*Farfantepenaeus duorarum*) are an economically important species in Biscayne Bay, FL, and support both food and bait commercial fisheries. Pink shrimp are also an important food resource for higher trophic level finfish species. This includes those fishes that support Florida's iconic and highly valued recreational flats fisheries—which have experienced a severe decline in recent decades and may be impacted by the pink shrimp fisheries. Despite their economic and ecological importance, few studies have evaluated the long-term trends in Biscayne Bay's pink shrimp fisheries. In this study, we evaluated over 30 years (1987–2020) of fisheries-dependent and economic data on the pink shrimp bait and food fisheries in Biscayne Bay with segmented regression to identify trends and potential breakpoints. We also evaluate trends in Biscayne Bay bonefish (*Albula vulpes*) over 25 years (1993–2018), based on recreational angler interview data, and assess potential interactions with the shrimp fisheries. We found that landings, value, effort, and participation (number of vessels and dealers) in both Biscayne Bay pink shrimp fisheries have exhibited declines from peaks in the late 1990s. No significant trends were detected in annual bonefish catch or catch per unit effort (catch/trip), but fishing effort declined over the time series. We did not find a significant relationship between annual bonefish catch per unit effort and commercial shrimp fishing landings or effort, suggesting that the pink shrimp fisheries are not a primary factor contributing to declines in the Biscayne Bay bonefish fishery.

Keywords Pink shrimp · Roller frame trawl · Wingnet · Flats fishery · *Farfantepenaeus duorarum*

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10641-022-01314-9.

R. J. Rezek (✉)
Department of Marine Science, Coastal Carolina University, 100 Chanticleer Dr E, Conway, SC, USA
e-mail: rrezek@coastal.edu

W. R. James · J. S. Rehage · R. O. Santos
Institute of Environment, Florida International University, Miami, FL, USA

W. R. James · V. Bautista · R. O. Santos
Department of Biological Sciences, Institute of Environment, Florida International University, 11200 SW 8th Street, Miami, FL 33199, USA

W. R. James · J. S. Rehage
Department of Earth and Environment, Institute of Environment, Florida International University, 11200 SW 8th Street, Miami, FL 331993, USA

I. Zink
St. Petersburg, FL, USA

Introduction

Pink shrimp (*Farfantepenaeus duorarum*) is a species of penaeid shrimp (Family Penaeidae) commonly

Published online: 06 August 2022

found in South Florida estuaries (Browder and Roblee 2009; Santos et al. 2018; James et al. This issue). Pink shrimp exhibit a life history pattern that includes migrating between nearshore juvenile nursery habitats and offshore adult habitats (Dall et al. 1990). This species is a major component of both the biomass and abundance of nearshore seagrass faunal communities (Santos et al. 2018). Pink shrimp are also economically important and support lucrative commercial fisheries throughout Florida (Johnson et al. 2012; Zink 2017). Within the past decade, Florida pink shrimp annual landings can be as high as 12.6 million pounds and can value as high as 24.1 million USD (Zink 2017). Pink shrimp fisheries in South Florida, including those of Biscayne Bay and Miami's surrounding offshore waters, contribute to this regional economic impact. Specifically, there are two commercial pink shrimp fisheries in Biscayne Bay: (1) a live bait fishery that supports recreational fishing, and (2) a food fishery for direct human consumption.

Biscayne Bay pink shrimp fisheries constitute only a small component of Florida's overall pink shrimp landings and ex-vessel value; however, both commercial shrimp fisheries in Biscayne Bay represent the Bay's most important fishery product (Johnson et al. 2012). The pink shrimp bait fishery uses roller-frame trawls, targeting juveniles inhabiting shallow (1–2 m) seagrass habitats within Biscayne Bay (Berkeley et al. 1985). This fishery operates year-round to fill orders from dealers that sell live shrimp to be used as bait (Berkeley et al. 1985). In contrast, the food fishery uses wingnets that target shrimp in the upper water column, typically near channels, canals, bridges, bay passes, and inlets as subadult shrimp emigrate to offshore waters (EDAW Inc. 2003; Johnson et al. 2012). As of 2000, the food fishery is seasonal, open from November until May (Johnson et al. 2012; https://myfwc.com/fishing/saltwater/commercial/). The size of pink shrimp collected between the two fisheries varies, with shrimp in the bait fishery typically ranging between 10 and 22 mm carapace length (juvenile/subadult) and the food fishery > 19 mm carapace length (subadult/adult) (Johnson et al. 2012).

A lack of food availability was the considered third most important factor leading to bonefish population decline among experienced anglers, after climate and water quality (Kroloff et al. 2019). Given the high economic value of the recreational Florida flats fishery ($465 million in 2012; Fedler 2013) and the perception of Biscayne Bay as among the most productive flats fishing grounds (Rehage et al. 2019), it is important to understand the catch and economic trends of the Biscayne Bay pink shrimp fisheries relative to those of the flats fisheries to identify possible interactions to better evaluate potential economic tradeoffs between these fisheries.

The analysis of long-term fisheries-dependent data has been commonly used to provide insight into the status and sustainability of fisheries populations (Maunder and Punt 2004; Santos et al. 2017; Gervasi et al. 2021). Metrics such as catch per unit effort (CPUE) have been used as a proxy of relative abundance, providing information on long-term trends in the population status of fisheries species (Maunder and Punt 2004; Gervasi et al. 2021). Fisheries-dependent data have been used to assess the response of recreational fish species to disturbances, identify and understand the drivers behind the decline of fisheries catch, and the economic impact of recreational fisheries (Santos et al. 2017, 2019; Gervasi et al. 2021). In addition, in combination with economic data (e.g., total value, average price/kg, number of dealers), these metrics can provide valuable insight into the socioeconomic dynamics that influence fishing effort across time, space, and fishery resources; as well as the broader economic impact and value of fisheries at the local and regional scale (Johnson et al. 2012; Brown et al. 2018).

The most comprehensive report on the two Biscayne Bay pink shrimp fisheries analyzed dealer-reported landings and effort data supplemented with available data from previous research (Johnson et al. 2012). This study of Biscayne Bay's pink shrimp fisheries only described fisheries trends up to 2005 (Johnson et al. 2012). Thus, there is a need to update this analysis to assess the current status and trends in the two pink shrimp fisheries, considering human population growth and changing demands on food resources, economic shocks, coastal landscape transformation, and extreme climate events that have occurred over the last 15 years (Carey et al. 2011; Santos et al. 2020; Wachnicka et al. 2020). Pink shrimp densities in Biscayne Bay are influenced mainly by salinity, temperature, water depth, and submerged aquatic vegetation cover (SAV; dominated by seagrass species in Biscayne Bay; Zink et al. 2018). Since 2005, these environmental variables in Biscayne Bay have experienced dynamic changes that could influence the abundance of pink shrimp populations, and subsequently, the pink shrimp fisheries within Biscayne Bay (Santos et al. 2018, 2020). For instance, changes in water quality, invasive and harmful algal blooms, and Hurricane Irma have led to spatially heterogeneous changes in the environmental conditions and SAV cover throughout Biscayne Bay (Carey et al. 2011; Millette et al. 2019; Santos et al. 2020; Wachnicka et al. 2020). In addition, US reliance on farmed and imported shrimp has increased over the last decade with the potential to influence local US shrimp fisheries (Asche et al. 2012), potentially including the demand and the economic incentives that drive food shrimp fishing efforts and participation in Biscayne Bay.

Pink shrimp serve as an important prey species for upper trophic level consumers such as bonefish *Albula vulpes* (Crabtree et al. 1998), a key target of the iconic high-value recreational Florida flats fishery (Adams and Cooke 2015). While these flats fisheries species are considered data-deficient (Adams et al. 2014, 2019), available data suggests that their populations have experienced a severe decline since the 1980s in Biscayne Bay (Santos et al. 2019) and more broadly throughout Florida (Santos et al. 2017, 2019; Kroloff et al. 2019; Rehage et al. 2019), although recent data points to a recovery in the population (Boucek et al. 2022). Fisheries that target benthic invertebrates and other lower trophic level consumers, such as the Biscayne Bay pink shrimp fisheries, can have substantial effects on ecosystems and their ability to support higher trophic level finfish (Smith et al. 2011; Eddy et al. 2017). Reduced food availability to these finfish species, as a result of pink shrimp fishing or associated bycatch, could be an important contributing factor to the recent declines in the bonefish fishery.

Penaeid shrimp were found to compose 7.7% of bonefish prey species by weight and were found in 23.4% of samples based on gut content analysis of bonefish in South Florida conducted by Crabtree et al. (1998). Additionally, species commonly caught as bycatch in the Biscayne Bay commercial shrimp fisheries are known to be important prey items for bonefish. Crabtree et al. (1998) found that Gulf toadfish (*Opsanus beta*) and portunid crabs composed 17.2% and 10.9% of bonefish prey species by weight, respectively. Gulf toadfish were the second most common bycatch species based on a fisheries independent roller-frame survey conducted in Biscayne Bay, with 43 caught per 1000 shrimp (Ault et al. 2001). Berkley et al. (1985) identified blue crab (*Callinectes sapidus*) as a common bycatch species in the Biscayne Bay shrimp fishery, with an estimated annual catch of 69,788; or 2 for every 1000 pink shrimp landed (as standardized by James et al. This issue). Although not evaluated as bycatch by Ault et al. (2001) and Berkley et al. (1985); xanthid crabs were found to compose 29.9% of bonefish prey (Crabtree et al. 1998), and, like other benthic decapods, are likely to be negatively impacted by roller frame fishing.

Considering that Biscayne Bay pink shrimp represents the Bay's most important commercial fisheries, with a potential to interact with one of the most important recreational flats fishery species, the primary goal of this study was to assess the status of Biscayne Bay pink shrimp fisheries by analyzing temporal trends in fisheries-dependent data. Secondarily, we examined the potential for interactions with the bonefish flats fishery in Biscayne Bay. We reviewed the long-term trends (> 30 years) of fisheries-dependent catch metrics to quantify changes in pink shrimp landings, fishing effort and participation (Objective 1), and economic value indicators to assess the economic impact of the pink shrimp fisheries in Biscayne Bay (Objective 2). The assessment of pink shrimp catch and economic value trends were used to characterize the evolution of the regional importance of both the bait and food fisheries and provide insight on the current status of pink shrimp fisheries in Biscayne Bay, both valuable information to stakeholders concerned about the sustainability of fisheries in South Florida. We then evaluate long-term (25 years) temporal trends in the Biscayne Bay recreational bonefish fishery based on recreational angler interview creel census data and tested for interactions with the commercial bait and food pink shrimp fisheries (Objective 3).

Methods

Data gathering and processing

We reviewed the long-term trends (> 30 years) of the commercial bait and food pink shrimp fishery catch and their economic value based on fishery-dependent time series. The landings, number of trips, and participation and economic value data were obtained from the Florida Fish and Wildlife Conservation Commission (FWC; myfwc.com) for all coastal waters on the Florida Atlantic Coast between 25° and 26° N latitude (Fig. 1), hereafter referred to as the Miami area. The fishery-dependent data for the bait shrimp fishery and food shrimp fishery ranged from 1987–2020 to 1989–2020, respectively. We used annual sums of total landings (kg), number of trips (effort), and mean CPUE (kg/trips) to assess the long-term dynamics of pink shrimp catch in Biscayne Bay. In addition, to quantify the relative importance of Biscayne Bay pink shrimp fisheries at the state level, total annual landings for the State of Florida (including pink shrimp landings in federal waters sold in Florida) were also obtained and evaluated relative to total State's landings. Direct data requests were made to FWC for spatially explicit annual pink shrimp bait and food fisheries landings data, which were available for 2003 to 2020 (see Fig. 1 for spatial regions) to evaluate the spatial distribution of landings in recent years.

The economic value of the pink shrimp fisheries was evaluated with three indicators: total estimated value of landings (2020 USD value of total kg landed), shrimp price (2020 USD/kg), and the total number of vessels and dealers (i.e., a business

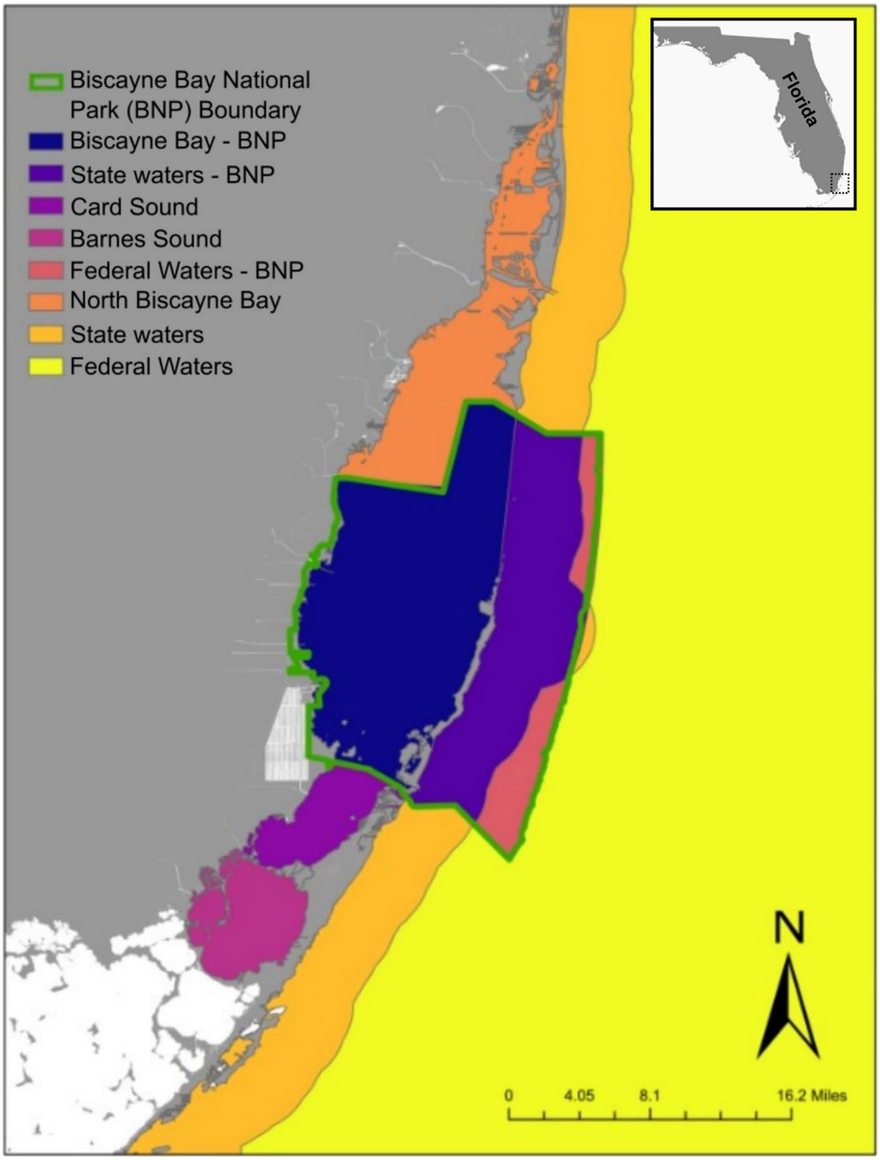


Fig. 1 Map of Biscayne Bay and surrounding waters with pink shrimp spatial fishing regions indicated, collectively referred to as Miami area. Areas within the boundaries of Biscayne Bay National Park (BNP) are indicated

or person who purchases or receives a federally managed species for the purpose of selling) participating in each fishery. Similar to the catch data, the total estimated value and price data for the pink shrimp bait and food fishery were available for 1987–2020 and 1989–2020, respectively. These two indicators were used to assess the economic impact and sustainability of both fisheries. We were also provided with the number of unique commercial vessels reporting landings per year for the pink shrimp bait and food fishery for 2003–2020 and 2000–2020, respectively, as well as the number of pink shrimp bait and food fishery dealers for 1987–2020 and 1989–2020, respectively. While the number of vessels and dealers can be used as indicators of fishing effort, in this study, we used them as an indicator of the personal/fishermen and commercial investment in the fisheries and instead use the number of fishing trips as effort.

Angler interview-based Biscayne Bay National Park (BNP) creel census data for the recreational bonefish fishery between 1993 and 2018 was used to assess temporal trends and potential interactions with the shrimp fisheries. This dataset was provided by the BNP and is based on voluntary interviews of recreational anglers in Biscayne Bay National Park, angler interviews in this database include trips that fished both within Biscayne Bay and surrounding waters (see Harper et al. 2000 for a detailed map). This fisheries-dependent dataset was collected and organized using the standardized method outlined in Davis and Thue (1979). The dataset was aggregated to include the annual number of angler interviews, representing fishing trips that indicated bonefish were targeted or landed, the number of trips reporting bonefish catch, and the number of bonefish caught. CPUE was calculated as the annual mean number of bonefish caught per trip. Trips that reported bonefish catch but did not indicate them as a target species represented 2% of the effort over the time series, and were included in the calculation of CPUE.

Statistical analyses

We performed analyses to quantify the overall trends of catch and economic value indicators as well as to identify major changes to the trends. To accomplish this, segmented regression was used to analyze trends in pink shrimp bait and food fisheries data and to identify significant changes in the slope in the time series based on the occurrence of breakpoints (i.e., change in trends). This type of analysis allows for assessing potential temporal thresholds in the data that simple linear regressions cannot capture. The segmented regressions were performed using the R package *segmented* (Muggeo 2003, 2008). If no breakpoints in the time series were detected, or if the breakpoint model was not significant ($\alpha > 0.05$), linear regression was used to analyze the overall trend. Pink shrimp landings data were converted from lbs to kg, and all economic fisheries data were adjusted for inflation to 2020 U.S. dollars prior to analysis based on mean annual Consumer Price Index values obtained from the Bureau of Labor Statistics (www.bls.gov/cpi). It should be noted that vessels reporting landings in the bait shrimp fishery may also report landings in the food fishery, and vice versa, within a given year.

Temporal trends in annual bonefish catch, effort (trips), and CPUE were evaluated using methods described for the shrimp fisheries above. Potential interactions between the bonefish recreational fishery and the pink shrimp commercial fisheries were evaluated with regressions relating annual bonefish CPUE to pink shrimp food and bait fishery landings and effort number of trips; with a significant relationship (with a negative regression coefficient) considered indicative of a harmful impact of the commercial shrimp fisheries on bonefish populations. The relationship between bonefish CPUE and food/bait shrimp fishery CPUE was evaluated to identify any potential relationship between bonefish and shrimp populations. Statistical analysis was conducted with R version 4.1 (R Core Team 2021). Data analyzed for this manuscript are available in the supplementary information (Table S1, S2, S3).

Results

Pink shrimp landings

Landings for the pink shrimp bait fishery exhibited less temporal variability than the pink shrimp food fishery (Fig. 2a). Biscayne Bay's pink shrimp bait fishery annual landings averaged 109,187 kg/year and ranged from 48,837 to 177,766 kg/year (Table S1). Landings exhibited an increasing trend between 1987 and 1998 at a rate of 9877 kg per year, after which landings decreased at a rate of 3988 kg/yr per year until 2020 (Fig. 3a, Table 1). The Biscayne Bay pink shrimp food fishery annual landings averaged 129,284 kg/year and ranged from 3053 to 460,131, with a trend of increasing landings between 1989 and 1998 at a rate of 28,799 kg/year, after which landings were variable and did not change significantly between 1998 and 2020 (Fig. 3b). Over the past 3 years (2018–2020), the bait fishery averaged 60,922.5 kg/year while the food fishery averaged 42,196.6 kg/year, which was in the lower end of the fisheries range over the time series (Table S1, S2).

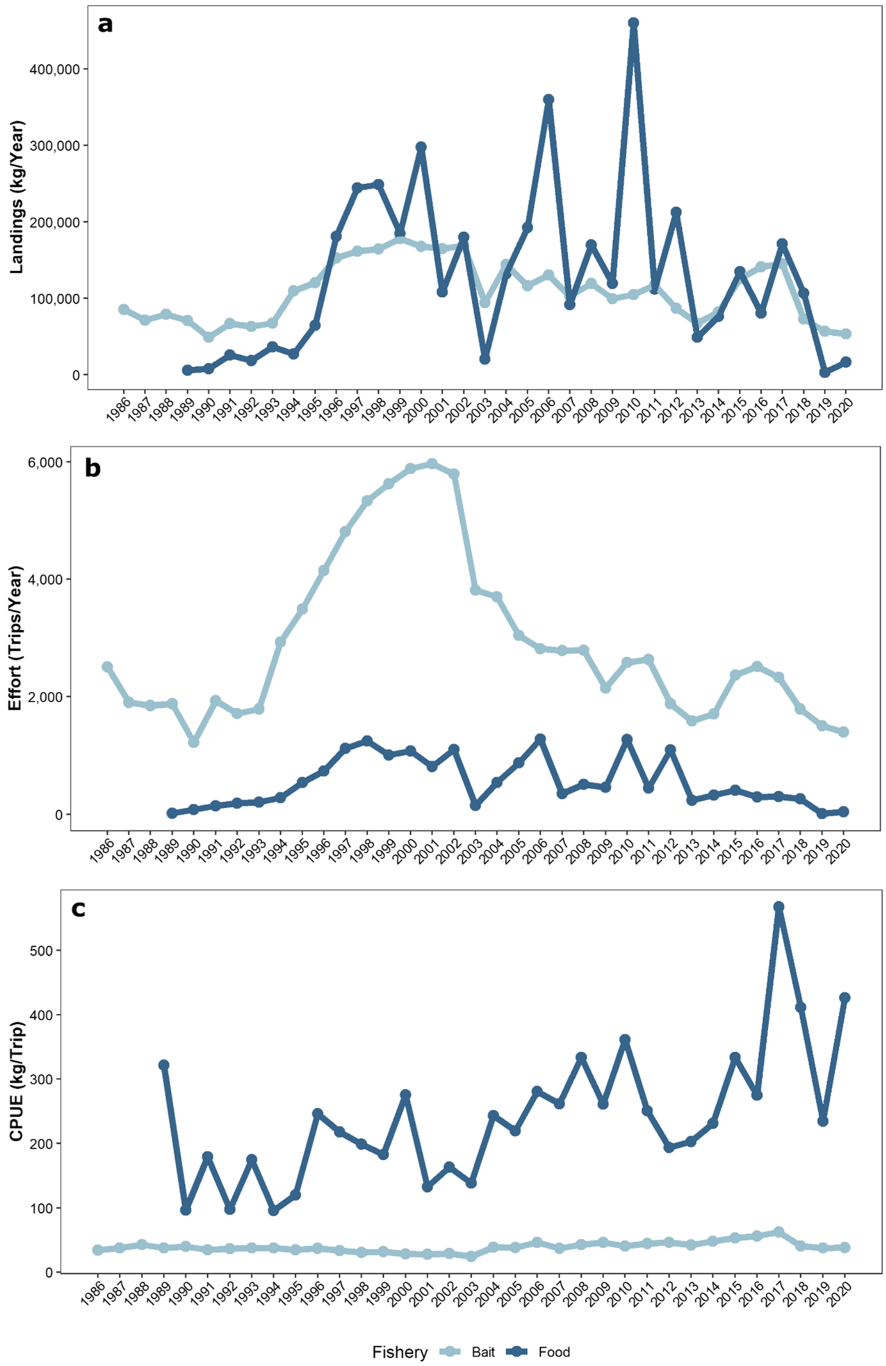


Fig. 2 Total landings (**a**), effort (**b**), and CPUE (**c**) of the Miami area bait and food fisheries

Pink shrimp effort

The overall effort was much higher for the pink shrimp bait fishery than the pink shrimp food fishery (Fig. 2b). The Miami area pink shrimp bait fishery's annual effort (fishing trips per year) averaged 2919.2 trips and ranged from 1226 to 5965 trips. Between 1987 and 1999, bait fishery effort increased at a rate of 349 annual trips/year. After 1999 the annual effort witnessed a decline at a rate of 194 trips/year (Fig. 3c, Table 1). The annual effort of the pink shrimp food fishery averaged 55 trips/year, and ranged from 13 to 1282 trips/year. Between 1989 to 1998, Miami's food fishery efforts increased at a rate of 132 trips/year, after 1998 the annual effort saw a decline at a rate of 40 trips/year until 2020 (Fig. 3d). From 2018 to 2020, effort was low for both fisheries with an average of 1566 trips for the bait fishery and 104 trips for the food fishery (Table S1, S2).

Pink shrimp catch per unit effort

The catch per unit effort (CPUE) was much lower for the pink shrimp bait fishery than the pink shrimp food fishery (Fig. 2c). The pink shrimp bait fishery mean annual CPUE was 39.4 kg/trip and ranged from 24.6 kg/trip to 62.2 kg/trip. The time series shows a decreasing trend between 1987 and 2001 at a rate of 0.8 kg/trip per year, after which CPUE increased at a rate of 1.6 kg/trip per year until 2017. The trend changes once again, highlighting a decreasing CPUE at a rate of 7.2 kg/trip per year between 2017 and 2020 (Fig. 3e, Table 1). The pink shrimp food fishery annual CPUE averaged 241.5 kg/trip, and ranged from 96.0 kg/trip to 567.3 kg/trip. No breakpoints were detected and a trend of increasing CPUE was found between 1989 and 2020 at a rate of 7.0 kg/trip per year (Fig. 3f). In the last 3 years, CPUE averaged 38.7 kg/trip for the bait fishery, with the food fishery an order of magnitude higher at 357.5 kg/trip.

Proportion of state pink shrimp landings

Overall, the relative contribution to the total state landings by the Miami area pink shrimp food fishery was small, and ranged mostly in the single digits, while the pink shrimp bait fishery was somewhat

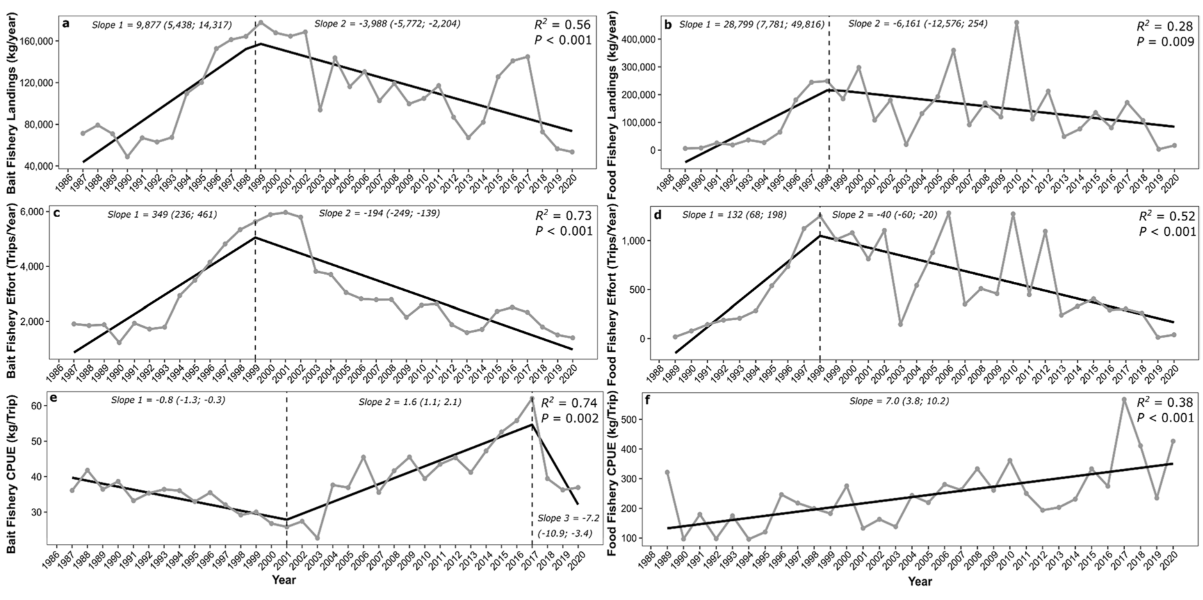


Fig. 3 Total landings of the Miami area commercial pink shrimp bait (**a**) and food (**b**) fishery (gray), Annual effort (fishing trips per year) for the Miami area commercial pink shrimp bait (**c**), and food (**d**) fishery (gray), and annual catch per unit effort (CPUE; kg per trip) for the Miami area commercial pink shrimp bait (**e**) and food (**f**) fishery (gray) with segmented regression results (black) and significant breakpoints indicated with vertical dashed lines. Overall model *P*-value and coefficient of determination (R^2) are annotated, and regression coefficients of segments (slopes) are annotated in italics with 95% confidence intervals (lower; upper). 95% confidence intervals that do not include 0 indicate significant change across the period

Table 1 Summary of the most recent trends in fisheries metrics and the year of the most recent trend change as determined by breakpoint analysis for the commercial bait and food pink shrimp fisheries and the recreational bonefish fishery in Biscayne Bay and surrounding waters. A lack of breakpoint in fisheries metric trends over the relevant time series is indicated with N/A

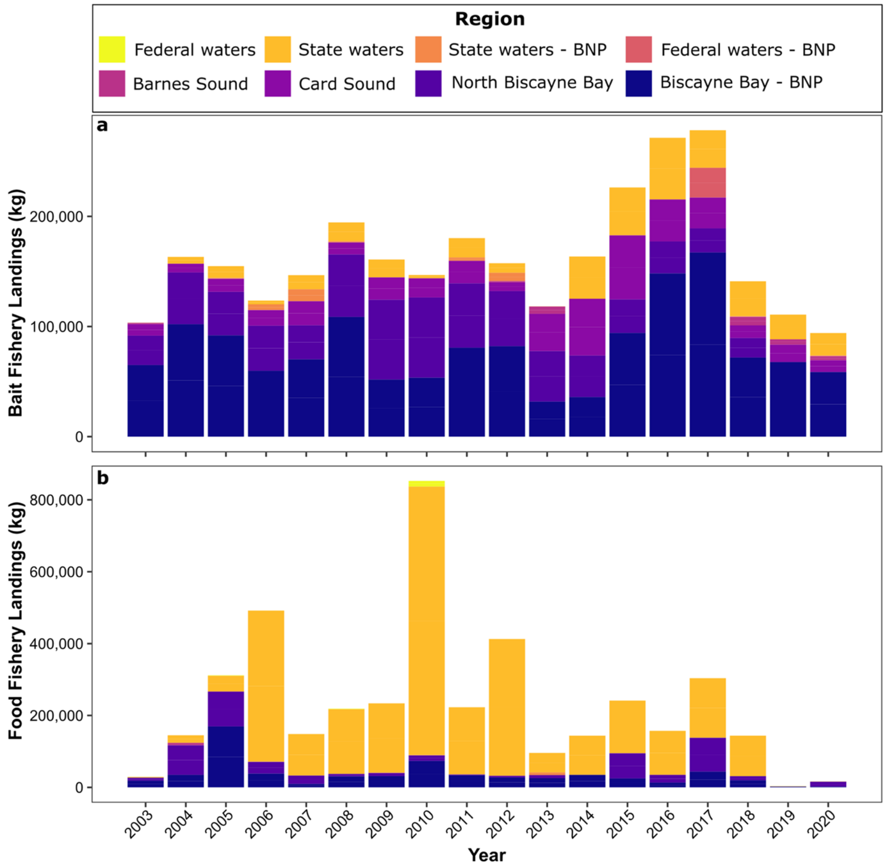
Fishery	Fisheries metric	Most recent trend	Year of last breakpoint
Bait shrimp			
	Landings	Decreasing	1998
	Effort	Decreasing	1999
	CPUE	Decreasing	2017
	% of state landings	Decreasing	1997
	Price	Decreasing	1994
	Fishery Value	Decreasing	N/A
	Vessel #	Decreasing	N/A
	Dealer #	Decreasing	1995
Food shrimp			
	Landings	Decreasing	1998
	Effort	Decreasing	1998
	CPUE	Increasing	N/A
	% of state landings	Decreasing	2010
	Price	Stable	1996
	Fishery Value	Decreasing	1998
	Vessel #	Decreasing	2012
	Dealer #	Stable	2011
Bonefish			
	Landings	Stable	N/A
	Effort	Decreasing	N/A
	CPUE	Stable	N/A

more substantial. The Biscayne Bay bait fishery comprised 14.0% of Florida's total landings on average and ranged from 5.2 to 21.0% of the state's bait landings over the time series, 1987–2020. Between 1987 and 1997, the proportion of Florida's total landings originating from the Miami area had an increasing trend at a rate of 1.0 pp (percentage point) of the state total per year, after 1997 the proportion of State landings originating from the Miami area decreased at a rate of 0.4 pp of the state total per year until 2020 (Fig. S1a, Table 1). The Miami area pink shrimp food fishery compromised 3.0% of Florida's total state landings on average and ranged from 0.1 to 11.4% of the state's food landings over the time series. Between 1989 and 2010, the proportion of Florida's total landings for shrimp consumption originating from the Miami area had an increasing trend at a rate of 0.7 pp of the state total per year, after 2010 the proportion of the state's landings originating from the Miami area decreased by 0.6 pp of the state total per year (Fig. S1b).

Spatial distribution of landings from 2003 to 2020

The majority of bait shrimp were caught within the Biscayne Bay proper—Biscayne Bay National Park (BNP) and North Biscayne Bay (Fig. 1)—with 72.2% of landings within the Bay, 14.1% occurring in Card and Barnes Sound, and 13.6% occurring in state or federal waters between 2003 to 2020 (Fig. 4a, Fig. S2a). Within Biscayne Bay, most bait shrimp landings originated from BNP—contributing 49.1% of total landings, and secondarily from North Biscayne Bay—contributing 23.1% of the total landings (Fig. 4a, Fig. S2a). In contrast, the majority of food shrimp were landed from nearshore state waters (72.0% on average), with the largest contribution of landings from being captured in nearshore state waters outside of BNP (72.2%; Fig. 4b, Fig. S2b). This pattern of high nearshore food shrimp landings was prevalent except for a handful of years at the start and end of the time series. Between 2003–2005 and 2019–2020, the

Fig. 4 Total landings in Miami area commercial pink shrimp bait (**a**) and food (**b**) fisheries from different regions of Biscayne Bay and Offshore waters. Regions within Biscayne Bay National Park (BNP) are indicated in the legend, the second level of the legend (Barnes Sound to Biscayne Bay — BNP) comprises regions within Biscayne Bay



majority of food landings (84.7% on average) occurred within Biscayne Bay; these years were characterized by relatively low annual total landings (between 1781 (0.6% of peak landings) and 155,883 kg (41% of peak landings; Fig. 4). Outside of these 5 years, state water landings comprised 80.2% of total food fishery landings.

Participation and economic value indicators

Overall, the average price (in inflation adjusted 2020 USD/kg) was higher for the pink shrimp bait fishery than the pink shrimp food fishery (Fig. 5a). The average price of the Miami area commercial pink shrimp bait fishery was 12.63 USD/kg, and ranged from 7.36 to 28.97 USD/kg. Between 1986 and 1994, Miami's bait shrimp fishery rapidly decreased in price at a rate of 0.75 USD/kg per year. After 1994, the price per kilogram of the bait fishery slowly declined with an adjusted rate of 0.06 USD per year (Fig. 6a, Table 1).

The average price of the Miami area commercial pink shrimp food fishery was 4.25 USD/kg and ranged from 2.26 to 11.18 USD/kg. Between 1989 and 1996, Miami's food shrimp fishery rapidly decreased in price per kilogram at a rate of 1.28 USD/kg per year. After 1996, the price per kg did not change significantly (Fig. 6b).

The total estimated annual value (landings × mean 2020 USD/kg) of the Miami area pink shrimp bait fishery was higher than the pink shrimp food fishery for every year in the time series (Fig. 5b). The pink shrimp bait fishery's estimated value adjusted for inflation averaged 1,313,600 USD per year, and ranged from 444,500 to 2,294,200 USD per year. A significant breakpoint was detected in 2002; however, the resulting segmented regression model was not significant, and a linear regression model was used to evaluate the overall trend. The total inflation-adjusted value of the bait shrimp fishery declined at a rate of 17,100 USD per year between 1987 and 2020 (Fig. 7a). The total estimated annual value of

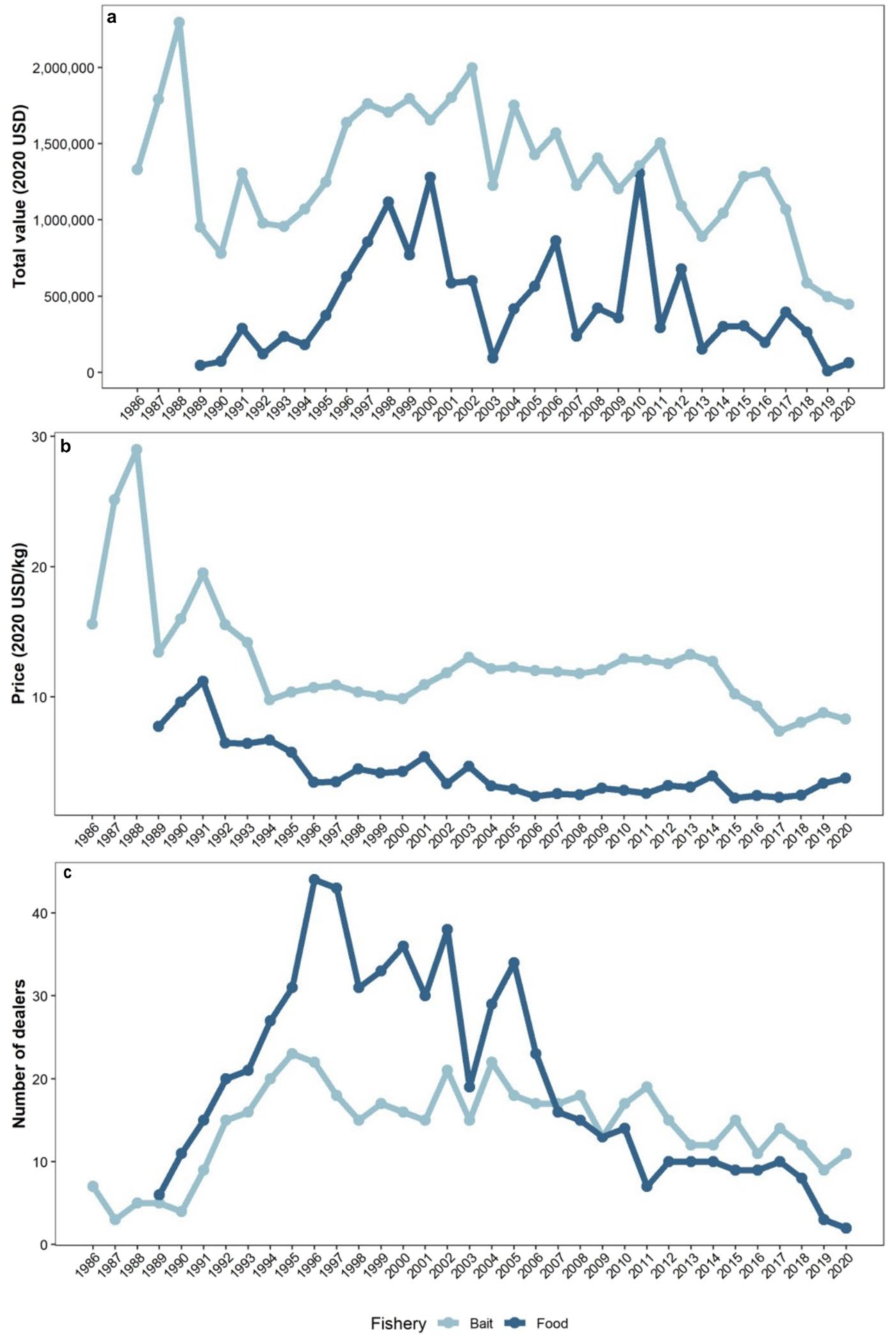


Fig. 5 Average price (**a**), total value (**b**), and the number of dealers (**c**) for the Miami area commercial pink shrimp bait and food fisheries. Price and value are expressed in inflation-adjusted 2020 U.S. Dollars

the Miami area pink shrimp food fishery adjusted for inflation averaged 439,428 USD per year and ranged from 10,299 to 1,306,668 USD per year. Between 1989 and 1998, Miami's food fishery increased in value at a rate of 99,200 USD per year. After 1998 Miami's pink shrimp food fishery value declined at a rate of 31,100 USD per year until 2020 (Fig. 7b).

Data for vessels was available beginning in 2003 and 2000 for the bait and food fisheries, respectively. The number of vessels in the pink shrimp bait fishery was less variable than for the pink shrimp food fishery. The number of vessels reporting pink shrimp bait fishery landings in the Miami area per year was 33 on average and ranged from 21 to 44 (Table S1).

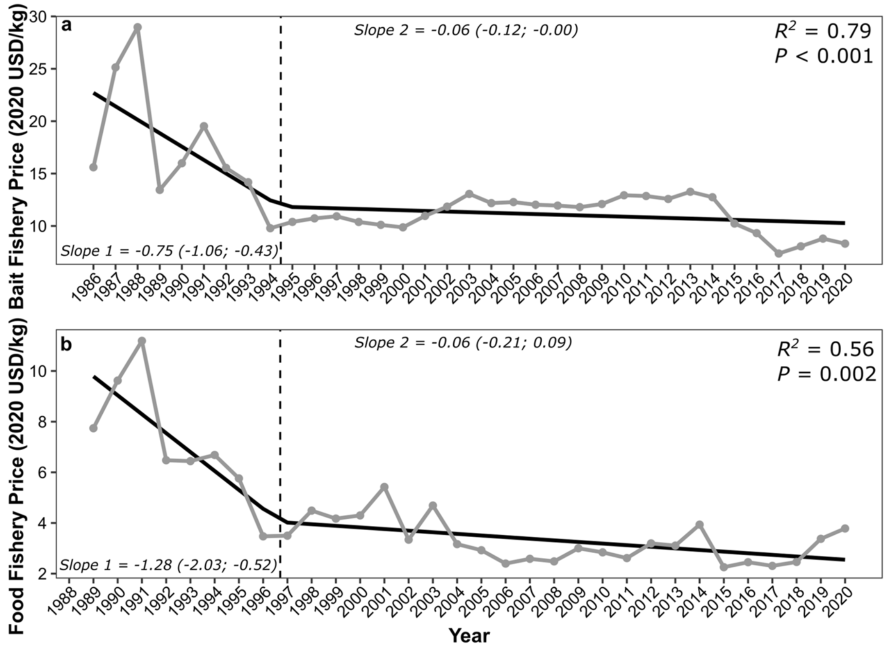


Fig. 6 Average price of the Miami area commercial pink shrimp bait (**a**) and food (**b**) fisheries in inflation-adjusted 2020 U.S. Dollars per kg (gray), with segmented regression results (black) and significant breakpoints indicated with vertical dashed lines. Overall model *P*-value and coefficient of determination (R^2) are annotated, and regression coefficients of segments (slopes) are annotated in italics with 95% confidence intervals (lower; upper). 95% confidence intervals that do not include 0 indicate significant change across the period

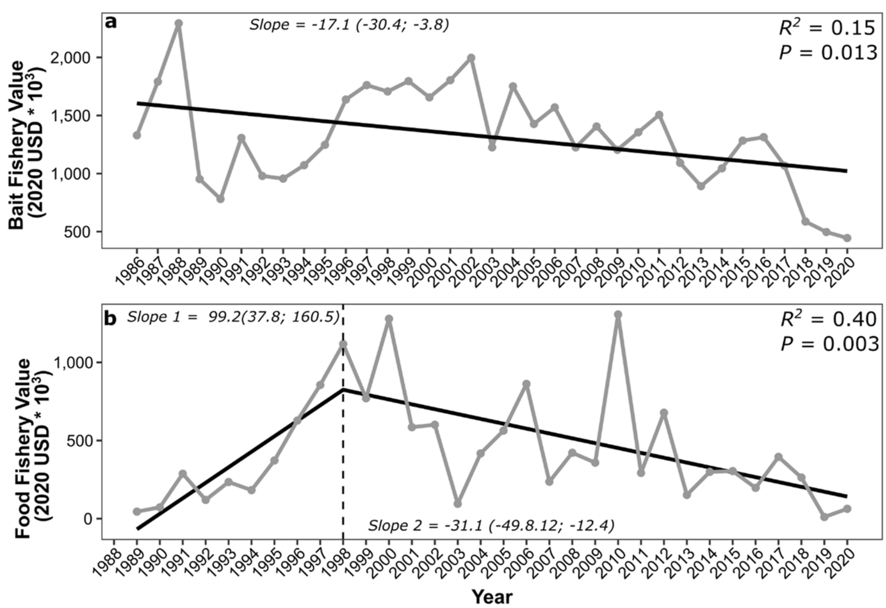


Fig. 7 Estimated annual total value of the Miami area commercial pink shrimp bait (**a**) and food (**b**) fisheries in inflation-adjusted 2020 U.S. Dollars (gray), with segmented regression, or regression, results (black), and significant breakpoints indicated with vertical dashed lines. Overall model *P*-value and coefficient of determination (R^2) are annotated, and regression coefficients of segments (slopes) are annotated in italics with 95% confidence intervals (lower; upper). 95% confidence intervals that do not include 0 indicate significant change across the period

No significant breakpoint was found in the number of vessels reporting bait shrimp. Effort declined by 0.7 vessels per year between 2000 and 2020 (Fig. 8a, Table 1). The annual number of vessels reporting pink shrimp food fishery landings in the Miami area per year was 59 on average and ranged from 1 to 137 (Table S2). Between 2000 and 2012, the state's food fishery increased the number of vessels at a rate of 4.2/year. After 2012, the number of food fishery vessels found in the Miami area declined at a rate of 10.5/year (Fig. 8b).

The number of reported dealers in the bait fishery was less variable over the time series compared to the food fishery (Fig. 5c). The annual number of reported dealers purchasing from Miami's bait fishery averaged 14 and ranged from 3 to 23. Between 1986

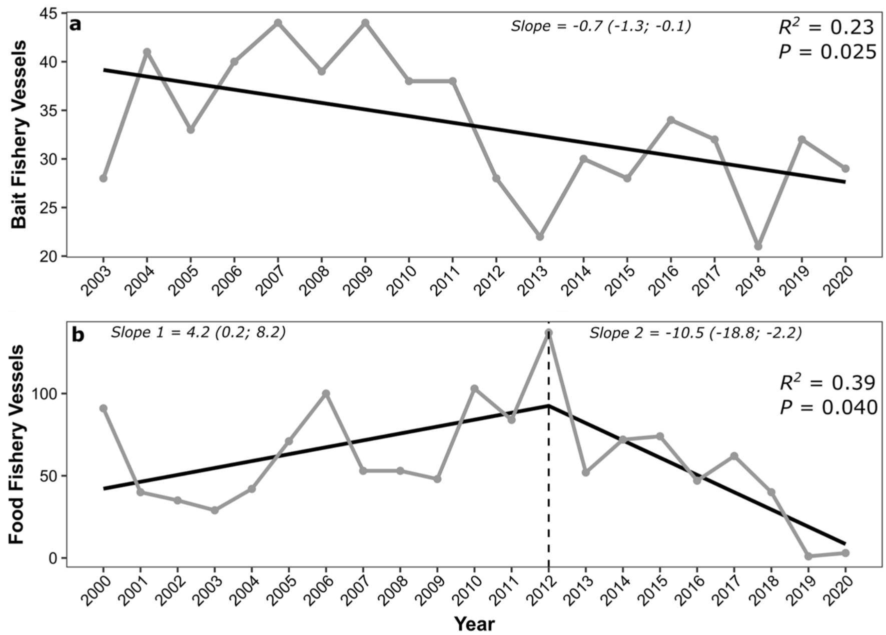


Fig. 8 Number of vessels reporting commercial pink shrimp bait (**a**) and food (**b**) fisheries landings from the Miami area annually (gray), with segmented regression, or regression, results (black) and significant breakpoints indicated with vertical dashed lines. Overall model *P*-value and coefficient of determination (R^2) are annotated, and regression coefficients of segments (slopes) are annotated in italics with 95% confidence intervals (lower; upper). 95% confidence intervals that do not include 0 indicate significant change across the period. The same vessel may report landings in both bait and food pink shrimp fisheries within a year

to 1995, the number of bait fishery dealers increased at a rate of 2.5 dealers/year. After 1995, the number of pink shrimp bait fishery dealers began to decline at a rate of 0.4 dealers/year (Fig. 9a). The number of reported dealers purchasing from Miami's food fishery per year averaged 20, and ranged from 2 to 44 dealers. Between 1989 and 1996, the number of food fishery dealers increased at a rate of 4.8 dealers/year. After 1996 the number of pink shrimp food fishery dealers began to decline at a rate of 2.1 dealers per year until 2011. The number of dealers did not change significantly between 2011 and 2020 (Fig. 9b).

Bonefish recreational fishery analysis

Based on recreational angler interviews between 1993 and 2018, the total number of bonefish reported caught was 321. Annual reported bonefish catch ranged from 0 in 2014 and 2018 to 54 in 2003 (Table S3). No significant relationship was found between annual bonefish catch and year (Fig. 10a, Table 1). A total of 655 trips targeting bonefish were reported by anglers over the time series, with the annual recreational bonefishing effort ranging from 1 trip in 2018 to 85 trips in 2002. A significant decline in bonefishing effort was found over time, decreasing at a rate of 1.17 trips/year between 1993 and 2018 (Fig. 10b). Bonefish CPUE ranged from 0 in 2014 and 2018 to 1.29 in 2011. No significant relationship was found between bonefish CPUE and year (Fig. 10c). There were no breakpoints detected in the time series of bonefish catch, effort, or CPUE. There was no significant relationship found between annual bonefish CPUE and pink shrimp bait fishery landings (Fig. 11a), effort (Fig. 11b), or CPUE (Fig. 11c). Likewise, there were no significant relationships detected between annual bonefish CPUE and pink shrimp food fishery landings, effort, or CPUE (Fig. S3a, b, c; $P > 0.05$).

Discussion

Pink shrimp fisheries represent the most important commercial fisheries in the in Biscayne Bay and the

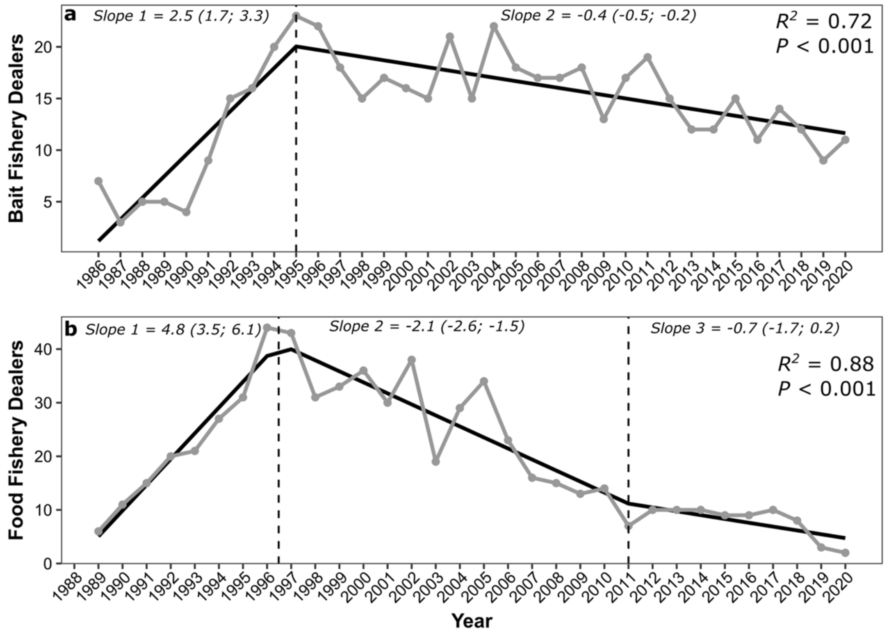


Fig. 9 Number of dealers purchasing from the Miami area commercial pink shrimp bait (**a**) and food (**b**) fisheries (gray), with segmented regression results (black) and significant breakpoints indicated with vertical dashed lines. Overall model P-value and coefficient of determination (R^2) are annotated, and regression coefficients of segments (slopes) are annotated in italics with 95% confidence intervals (lower; upper). 95% confidence intervals that do not include 0 indicate significant change across the period

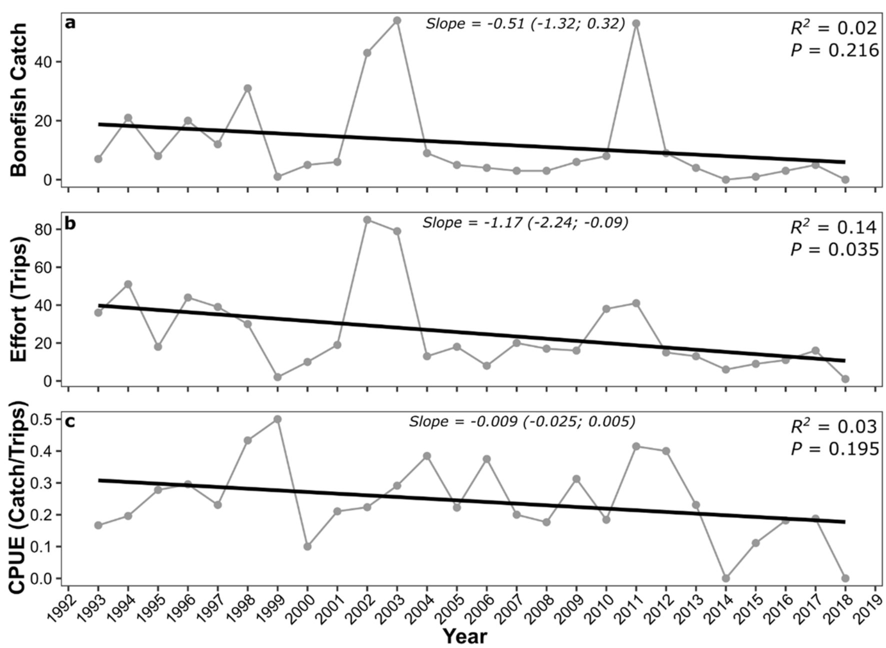


Fig. 10 Annual reported bonefish catch (**a**), number of trips targeting bonefish (**b**), and bonefish catch per unit effort (CPUE) (**c**), reported from recreational angler interviews in the Miami area. Regression P-value and coefficient of determination (R^2) are annotated, and regression coefficients are annotated in italics with 95% confidence intervals (lower; upper)

surrounding waters. Considering the human demography and environmental changes experienced in Biscayne Bay over the last decade, we designed this study to assess the status of Biscayne Bay pink shrimp fisheries by analyzing the temporal trends in fisheries-dependent data, especially since 2005. Both the pink shrimp bait and food fisheries in Biscayne Bay displayed dynamic changes throughout this study (1986–2020). In general, the pink shrimp food fisheries showed generally higher and more variably yearly landings than the bait fishery. Instead, the bait fishery exhibited higher effort, and lower CPUE than the food fishery. Still, due to a higher average price/kg throughout the time series, the bait fishery had a

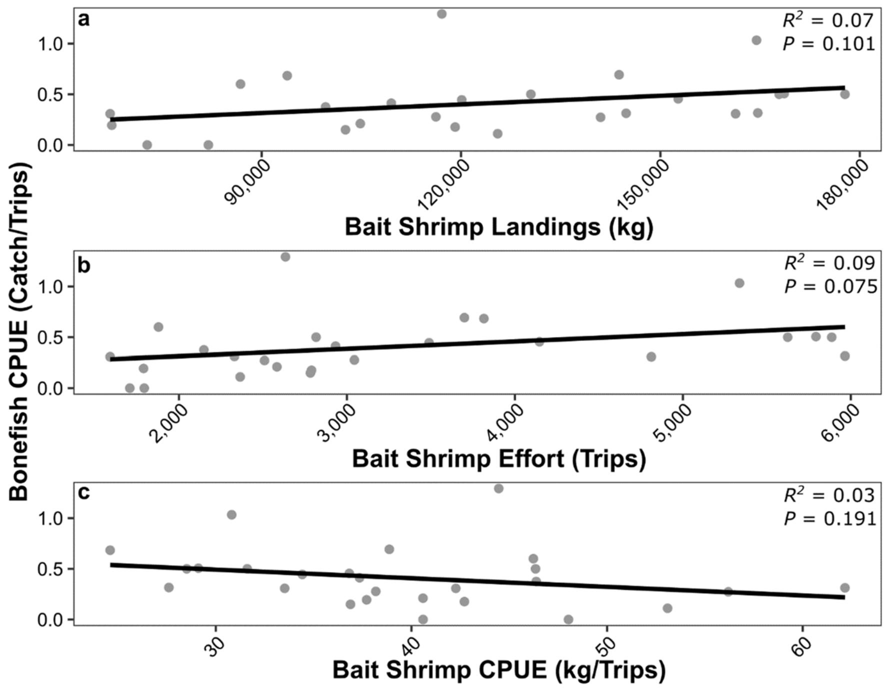


Fig. 11 Results of linear regression on the relationship between annual bonefish CPUE (catch per trip that targeted or landed bonefish) from recreational angler interviews with annual commercial bait shrimp fisheries landings (**a**), effort (**b**), and CPUE (**c**), in the Miami area. Regression *P*-value and coefficient of determination (R^2) are annotated

higher total estimated value than the food fishery for every year of comparison (1989 to 2020). The number of food shrimp dealers was initially greater than bait shrimp dealers between 1989 and 2006; however, after 2006 the number of bait dealers was greater than food shrimp dealers in the Miami area. The pink shrimp food fishery generally involved more vessels throughout the time frame of comparison, with the exception of 2019 and 2020, where a sharp decrease in vessels reporting food shrimp landings occurred. Over the full-time series, the food fishery experienced the largest decline across the catch and economic value indicators. While not considered in the present assessment of Biscayne Bay pink shrimp commercial fisheries trends, substantial recreational food shrimp fishing occurs as evidenced by the numerous lights observed shrimping in the vicinity of Bear Cut (Johnson et al. 2012; I. Zink Pers. Obs.). Presently, no data is collected on these landings, efforts, or other characteristics of recreational shrimpers.

Nearly all fisheries and economic metrics evaluated for both the food and bait shrimp fisheries in Biscayne Bay are currently in decline, reflecting a general decrease in the importance of their impacts on the economy and ecosystem. The only metrics that were not found to currently be in decline for both fisheries were the food shrimp price/kg, dealer number, and CPUE. For several metrics, the last 2 years represented the lowest values of the time series. The food shrimp fishery exhibited a particularly marked decrease in participation, with only 1 vessel reporting landings in 2019 and 3 vessels in 2020 compared to the average of 59 vessels reporting landings per year over the time series. The total value of the food fishery over these 2 years combined (73,230 2020 USD) was the lowest of any 2-year period in the time series, with 3 or fewer dealers purchasing shrimp per year. While vessel participation remained active in the bait shrimp fishery in 2019 and 2020 (32 and 29 vessels, respectively), the total combined value (941,454 2020 USD) and landings (109,980 kg) over years were the lowest of any 2-year period of the time series. These most current values indicate the bait shrimp fishery, though in decline, remains active in Biscayne Bay, while the food shrimp fishery is currently in a state of near abandonment.

Trends in CPUE in shrimp fisheries

Catch per unit effort (CPUE) from fisheries dependent data is often used as a proxy for the relative abundance of the target species, but there is not always a relationship between CPUE and abundance (Richards and Schnute 1986; Haggarty and King 2006). Johnson et al. (2012) reported a significant correlation between CPUE in the Biscayne Bay bait fishery from 2002 to 2005 and fisheries independent data on pink shrimp density, supporting the efficacy of fisheries dependent CPUE as a proxy of population size. Nevertheless, it is essential to consider statistical standardization procedures to account for potential biases related to fishing dynamics and angler behavior, which may cause a CPUE deviation from real abundance estimates of the targeted populations (Maunder and Punt 2004; Santos et al. 2017; Gervasi et al. 2021).

Our results showed a decrease in CPUE following 2017 for the bait fishery. Declines in the CPUE could be related to declines in abundance as the result of disturbances in Biscayne Bay, such as Hurricane Irma (2017), decreasing water quality, or changes in recruitment dynamics outside of Biscayne Bay (Carey et al. 2011; Zink et al. 2018; Santos et al. 2020; Wachnicka et al. 2020). These declines are likely not related to fishing pressure because effort and landings for the bait fishery had been declining for nearly 20 years at the time of the decline in CPUE. Deciphering this trend may also be complicated as bait shrimpers operate on a per-order basis (Ault et al. 1997; Johnson et al. 2012); the lower CPUE (kg/trip) may also reflect declining market demand for shrimp. Although not associated with significant breakpoints, landings and effort in the 3 years following Hurricane Irma (2018–2020) have been among the lowest values in the time series for both shrimp fisheries.

In the pink shrimp food fishery, there is a disconnect between the effort and the landings. At the beginning of the time series, both landings and effort increased together, but after 1998, the landings displayed a non-significant trend, while the effort has continually decreased. Unlike the bait fishery, the food fishery is only open from November to May, and the majority of landings are in nearshore waters outside of Biscayne Bay. Based on the life cycle of pink shrimp in Biscayne Bay, the peak of pink shrimp subadult emigration to offshore waters coincides with the seasonal opening of the food fishery (Berkeley et al. 1985; Criales et al. 2000). Food fishermen target shrimp emigrating from Biscayne Bay at bridges, channels, and canals which aggregate large densities as they emigrate from the Bay and increase catch but are not a preferred habitat of pink shrimp (EDAW Inc. 2003; Johnson et al. 2012; James et al. This issue). Other studies had found a disconnect between CPUE and abundance when the fishery was not operating in the preferred habitat of the target species (Haggarty and King 2006). The increase in CPUE over the study period could also be related to shifts in the phenology of pink shrimp (i.e., changes in the timing of emigration or timing of peak recruitment and subsequent development) and/or related to changes in environmental conditions over time (Visser and Both 2005). Additionally, improvements in the gear of the food fishery or behavioral changes of fishermen could contribute to the increase in CPUE trends (Maunder and Punt 2004). Since 2012, there has been a decline in the number of vessels in the food fishery (Fig. 8b). This decline could result from vessels with less successful yields exiting the fishery and leaving the catch to more experienced and conditioned vessels, fishing effort dynamics that can lead to increases in CPUE.

Spatial concentration of pink shrimp fisheries in Biscayne Bay and adjacent nearshore waters

As expected, the two fisheries were spatially distinct. Landings in the pink shrimp bait fishery are concentrated within the Bay, and this observation confirms previous studies that have documented that the majority of effort of the pink shrimp bait fishery, which targets smaller shrimp, occurs within Biscayne Bay (Berkeley et al. 1985; Ault et al. 1997; Johnson et al. 2012). This reflects the behavior and habitat associations exhibited by the differing ontogenetic stages/sizes targeted by each fishery: the bait fishery targets juveniles residing in seagrass nursery habitats, which occur within the Bay, while the food fishery targets subadults emigrating from Biscayne Bay (Crabtree et al. 1998; Hammerschlag et al. 2010). Between 2003 and 2020, the second highest landings (behind Biscayne National Park) for the bait fishery occurred in North Biscayne Bay, but in recent years (around 2015–2016) the proportion of the landings from North Biscayne Bay has decreased, with a corresponding increase in landings from nearshore state waters outside of Biscayne Bay. One hypothesis for this decrease of landings in this region could be that poor water quality in recent years within the northern region of Biscayne Bay could be creating poor habitat conditions for pink shrimp leading to lower abundances in this region of Biscayne Bay (e.g., eutrophication, seagrass habitat loss, hypoxia events, and high freshwater discharges; Millette et al. 2019; DERM 2021); indeed, substantial losses of seagrasses have been observed since 2016 in parts of North Biscayne Bay. Further investigation is needed to understand this spatial shift because it could have consequences on the sustainability of the fishery.

The majority of landings in the pink shrimp food fishery were retained from the nearshore in state waters, which coincides with previous studies characterizing that the bait and food fisheries as spatially distinct (EDAW Inc. 2003; Johnson et al. 2012). In certain years (2003–2005, 2019–2020), the majority of landings occurred from regions within Biscayne Bay, and these years corresponded with years with low total annual landings, with three (2003, 2019, and 2020) being some of the lowest landings over the time series. Because years with high landings focus on nearshore waters outside of Biscayne Bay, yearly conditions may be forcing fishermen to focus efforts within the Bay. These factors are likely related to a decrease in the abundance of migrating shrimp during the food fishery season, but factors affecting the ability to operate (e.g., weather conditions, gas prices) could also factor into shifts in the location of landings.

Shifts in shrimp fishing effort and economic value

Both pink shrimp fisheries in Biscayne Bay have decreased effort since a peak in the late 1990s, and economics are likely playing a role in the patterns observed. This observation is most apparent in the food fishery and is likely related to the decline in the average annual price/kg. The average annual price/kg declined from the beginning of the study period until 1997 when the price stabilized. The following year (1998), the trend of increasing effort ended, and effort within the food fishery in Biscayne Bay began a period of decline that persisted throughout the rest of the study period. The bait fishery had a similar pattern in the average annual price/kg, but the price stabilization happened earlier in 1995. Like the food fishery, the bait fishery time series exhibited an initial increase in effort until 1999, and the effort has had a decreasing trend since that date. There is a lag of 4 years between the stabilization of the lower annual price/kg in the bait fishery and a decline in effort that is not found in the food fishery. The difference in demand/needs between the two fisheries could be leading to the immediate or lagged response in effort to the annual price/kg seen between the two fisheries.

In the food fishery, the highest percentage Biscayne Bay contributed to state landings was 11.4% in 2010 and was the only year in which the percentage was greater than 10%. Since this peak the percentage of state total has rapidly decreased, and less than 0.5% of state landings were from Biscayne Bay in 2019 and 2020, indicating that the Biscayne Bay food fishery in its current state is of very low economic importance regionally. The bait fishery in Biscayne Bay is more important to the total Florida pink shrimp bait landings, contributing to as much as 21%. However, Biscayne Bay landings contributions are in decline, with 2020 representing the lowest contribution to pink shrimp bait landings in the entire timeseries at 5.2%.

Trends in the recreational bonfish fishery and potential interactions with shrimp fisheries

The use of CPUE as an estimate of relative abundance of recreational fisheries species on recreational angler creel interview data has been established in South Florida fisheries (Harper et al. 2000; Cass-Calay and Schmidt, 2009). Harper et al. (2000) found that BNP creel census CPUE (landings per trip) data were similar to CPUE data (abundance per sample) obtained from fisheries independent visual surveys conducted by the Southeast Fisheries Science Center between 1988 and 1991 for the top 10 most targeted species, indicating that the BNP creel surveys are an effective means of evaluating population trends. Biases that may influence creel survey fisheries data include the lack of interviews conducted at night and the lack of coverage of anglers that utilize private docks.

Based on an analysis of professional guide logbooks Santos et al. (2019) found recreational flats fisheries populations have been in decline in Biscayne Bay. Although the exact mechanism for this decline is not known, it has been hypothesized that the Biscayne Bay pink shrimp fisheries may have contributed due to associated declines in food availability (Kroloff et al. 2019). Both pink shrimp fisheries target and remove an important prey item for bonefish, and while the information on the bycatch of the food fishery is virtually nonexistent, it has been established that other important prey species for bonefish and other flats fishery species are caught as bycatch by bait fishery roller-frame trawl gear and removed from Biscayne Bay (Berkeley et al. 1985; Ault et al. 2001; Stallings et al. 2014). However, the amount of pink shrimp removed by the bait fishery is believed to be a relatively small proportion of the total Biscayne Bay population, with estimates ranging from 5.2% (Johnson et al. 2012) to 8–9% (Campos and Berkeley 2003).

Although Santos et al. (2019) identified declining bonefish CPUE in Biscayne Bay between 1975 and 2015, a more recent analysis of fishing tournament data from Biscayne Bay and the Florida Keys indicates that bonefish populations may be recovering (Boucek et al. 2022). The number of bonefish caught per boat day between 2015 and 2021 was more than double those between 1999 and 2014 (Boucek et al. 2022). This study partially coincides with a period of decline in flats fisheries observed in by Santos et al. (2019), as well as a period of recovery identified by (Boucek et al. 2022). Our analysis did not find a significant trend in bonefish CPUE between 1993 and 2018 based on BNP creel survey data. The dataset analyzed by Santos et al. 2019 ranged from 1975 and 2015 (40 years), and therefore was able to capture a stronger effect in bonefish fisheries trends influenced by greater annual CPUE reports by guides in the 1970s and 1980s, before the angler interview-based creel dataset used in this study which began. Bonefish CPUE values did consistently increase each year between 2014 and 2017, but unlike the findings of (Boucek et al. 2022), these values remained below the average over the time series. The significant decrease in recreational bonefishing efforts found in this study may reflect a decrease in populations or spatial shift in a fishing effort not captured by the analysis of CPUE.

There do not appear to be any clear trends in the pink shrimp fisheries that would explain the decline in the bonefish flats fisheries, as no negative association was found between pink shrimp bait and food fishery effort or landings and bonefish CPUE. Furthermore, a positive but non-significant trend was observed between bonefish CPUE and bait pink shrimp fisheries landings and effort, raising the possibility that interannual variations in environmental conditions, such as climate, water quality, and habitat quality (Kroloff et al. 2019), maybe a more important factor in mediating both pink shrimp fisheries production and bonefish populations. However, the lack of relationship between bonefish CPUE and pink shrimp CPUE indicates a weak association, if any, between interannual shrimp and bonefish populations. Based on these results, we hypothesize that the two pink shrimp fisheries in Biscayne Bay in their current state have a minimal impact on the recreational bonefish flats fisheries.

Conclusions

Here, we investigated the trends of the two commercial pink shrimp fisheries in Biscayne Bay using over 30 years of fishery and economic data, and their potential interaction with the recreational bonefish flats fishery based on a 25-year angler interview-based dataset. Both shrimp fisheries displayed dynamic changes during the study period that may reflect changes in pink shrimp abundance, environmental disturbances, socioeconomic factors, and interactions among these factors. For the bait fishery, the majority of landings were retained from within Biscayne Bay, and initial increases in both effort and landings shifted in the 1990s to trends of decreased effort and landings. The estimated total value in 2020 USD has decreased over the study period. The majority of landings from the food fishery were in nearshore waters. Like the bait fishery, the food fishery saw an initial increase in both landings and effort followed by decreasing effort; however, landings displayed a nonsignificant change in the same period. The CPUE for the bait fishery showed periods of increase and decrease and monthly CPUE appears to be a good proxy for monthly pink shrimp abundance in Biscayne Bay, but further investigation would be needed with a longer time series to substantiate and better characterize this relationship.

Over 25 years, annual recreational flats fishing effort targeting bonefish declined in Biscayne Bay and the surrounding waters, although, bonefish catch and CPUE did not change significantly over the time series. There was no relationship found between bonefish CPUE and commercial bait/food pink shrimp fishing landings, effort, or CPUE, suggesting that the pink shrimp fisheries do not have a major impact on bonefish populations in Biscayne Bay. Still, there is a need for studies that quantify the landings and value of the Bay's pink shrimp recreational fishery as well as a better characterization of the direct/indirect economic value and ecological impact (e.g., bycatch, habitat destruction) of both commercial fisheries. These types of studies would allow for robust insight on the cost–benefit tradeoffs of conservation strategies concerning the pink shrimp fisheries in Biscayne Bay. Given the overall decline in Biscayne Bay pink shrimp fishery vessels, effort, and landings, as well as the lack of any clear association between shrimp fisheries and the recreational bonefish flats fisheries, we conclude that the influence of the pink shrimp fisheries on the flats fishery is likely to be minimal in their current state.

Acknowledgements We would like to thank Chris Bradshaw of the Florida Fish and Wildlife Conservation Commission for his help in obtaining commercial shrimp fisheries data, and the Biscayne Bay National Park for providing recreational bonefish fisheries data. We acknowledge the Bonefish and Tarpon Trust for funding the development of this study through the Florida International University Foundation. This research was conducted in collaboration with the National Science Foundation through the Florida Coastal Everglades Long-term Ecological Research Program under DEB-1237517 and DEB-1832229. This is contribution #1474 from the Coastlines and Oceans Division in the Institute of Environment at Florida International University. No approval from research ethics committees was required to accomplish the goals of this study because no animals were used.

Funding Funding for preparing this study was received from the Bonefish and Tarpon Trust.

Data availability Data analyzed for this manuscript are available in the supplementary materials.

Declarations

Competing interests The authors declare no competing interests.

References

Adams AJ, Cooke SJ (2015) Advancing the science and management of flats fisheries for bonefish, tarpon, and permit. Environ Biol Fish 98:2123–2131. https://doi.org/10.1007/s10641-015-0446-9

Adams AJ, Horodysky AZ, McBride RS et al (2014) Global conservation status and research needs for tarpons (Megalopidae), ladyfishes (Elopidae) and bonefishes (Albulidae). Fish Fish 15:280–311. https://doi.org/10.1111/faf.12017

Adams AJ, Rehage JS, Cooke SJ (2019) A multi-methods approach supports the effective management and conservation of coastal marine recreational flats fisheries. Environ Biol Fish 102:105–115. https://doi.org/10.1007/s10641-018-0840-1

Asche F, Bennear LS, Oglend A, Smith MD (2012) U.S. shrimp market integration. Mar Resour Econ 27:181–192. https://doi.org/10.5950/0738-1360-27.2.181

Ault JS, Serafy JE, DiResta D, Dandelski J (1997) Impacts of commercial fishing on key habitats within Biscayne National Park. Biscayne National Park. Annual Report on Cooperative Agreement No. CA-5250–6–9018 to Biscayne National Park. 80 pp

Ault JS, Smith SG, Meester GA et al (2001) Site characterization for Biscayne National Park : assessment of fisheries resources and habitats. NOAA Technical Memorandum NMFS-SEFSC-468

Berkeley SA, Pybas DW, Campos WL (1985) Bait shrimp fishery of Biscayne Bay. Florida Sea Grant Extension Program, Technical Paper No. 40

Boucek RE, Rehage JSR, Castillo NA, Dwoskin E, Lombardo SM, Santos R, Navarre C, Larkin M, Adams A (2022) Using recreational tournament records to construct a 53-year time-series of the Florida Keys recreational Bonefish fishery. Environ Biol Fish. https://doi.org/10.1007/s10641-022-01299-5

Browder JA, Robblee MB (2009) Pink shrimp as an indicator for restoration of everglades ecosystems. Ecol Ind 9:S17–S28. https://doi.org/10.1016/j.ecolind.2008.10.007

Brown CE, Bhat MG, Rehage JS et al (2018) Ecological-economic assessment of the effects of freshwater flow in the Florida Everglades on recreational fisheries. Sci Total Environ 627:480–493

Campos WL, Berkeley SA (2003) Impact of the commercial fishery on the population of bait shrimp (Penaeus spp.) in Biscayne Bay 1986. NOAA Univ. Miami Joint Publ. NOAA Tech. Memo. NOS NCCOS CCMA 165:34 [orig. publ. 1986]

Carey RO, Migliaccio KW, Li Y et al (2011) Land use disturbance indicators and water quality variability in the Biscayne Bay Watershed, Florida. Ecol Ind 11:1093–1104. https://doi.org/10.1016/j.ecolind.2010.12.009

Cass-Calay SL, Schmidt TW (2009) Monitoring changes in the catch rates and abundance of juvenile goliath grouper using the ENP creel survey, 1973–2006. Endang Species Res 7:183–193. https://doi.org/10.3354/esr00139

Crabtree RE, Stevens C, Snodgrass D, Stengard FJ (1998) Feeding habits of bonefish, *Albula vulpes*, from the waters of the Florida Keys. Fish Bull 96:754–766

Criales, MM, Bello MJ, Yeung C (2000) Diversity and recruitment of penaeoid shrimps (Crustacea: Decapoda) at Bear Cut, Biscayne Bay, Florida, USA. Bull Mar Sci 67:773–788

Dall W, Hill BJ, Rothlisberg PC, Sharples DJ (1990) The biology of the Penaeidae. In: Advances in Marine Biology. Academic Press, London

Davis GE, Thue EB (1979) Fishery data management handbook, Everglades National Park. South Florida Research Center Report T-546. 77 pp

DERM (2021) Miami-Dade Biscayne Bay Report Card. https://mdc.maps.arcgis.com/apps/MapSeries/index.html?appid=bea607f9b3ed40bc88e51807a4c544a5. Accessed 5 Aug 2022

EDAW Inc. (2003) Biscayne National Park ethnographic overview and assessment. Biscayne National Park. https://permanent.fdlp.gov/LPS112621/bisc_ethno.pdf. Accessed 5 Aug 2022
Eddy TD, Lotze HK, Fulton EA et al (2017) Ecosystem effects of invertebrate fisheries. Fish Fish 18:40–53. https://doi.org/10.1111/faf.12165
Fedler A (2013) Economic impact of the Florida keys flats fishery. Bonefish & Tarpon Trust. https://lkga.org/wp-content/uploads/2017/05/btt-keys-economic-report.pdf. Accessed 5 Aug 2022
Gervasi CL, Santos RO, Rezek RJ et al (2021) Bottom-up conservation: using translational ecology to inform conservation priorities for a recreational fishery. Can J Fish Aquat Sci 1–16. https://doi.org/10.1139/cjfas-2021-0024
Haggarty DR, King JR (2006) CPUE as an index of relative abundance for nearshore reef fishes. Fish Res 81:89–93. https://doi.org/10.1016/j.fishres.2006.05.015
Hammerschlag N, Ovando D, Serafy J (2010) Seasonal diet and feeding habits of juvenile fishes foraging along a subtropical marine ecotone. Aquat Biol 9:279–290. https://doi.org/10.3354/ab00251
Harper DE, Bohnsack JA, Lockwood BR (2000) Recreational fisheries in Biscayne National Park, Florida, 1976–1991. Mar Fish Rev 62:8–26
James WR, Bautista V, Rezek RJ, et al (This issue) A review of the potential impacts of commercial inshore pink shrimp fisheries on the recreational flats fishery in Biscayne Bay, FL, USA. Environ Biol Fish
Johnson DR, Browder JA, Brown-Eyo P, Robblee MB (2012) Biscayne Bay commercial pink shrimp, *Farfantepenaeus duorarum*, fisheries, 1986–2005. Mar Fish Rev 74:28–43
Kroloff EKN, Heinen JT, Braddock KN et al (2019) Understanding the decline of catch-and-release fishery with angler knowledge: a key informant approach applied to South Florida bonefish. Environ Biol Fish 102:319–328. https://doi.org/10.1007/s10641-018-0812-5
Maunder MN, Punt AE (2004) Standardizing catch and effort data: a review of recent approaches. Fish Res 70:141–159. https://doi.org/10.1016/j.fishres.2004.08.002
Millette N, Kelble C, Linhoss A et al (2019) Using spatial variability in the rate of change of chlorophyll a to improve water quality management in a subtropical oligotrophic estuary. Estuaries Coasts 42:1792–1803
Muggeo VM (2003) Estimating regression models with unknown break-points. Stat Med 22:3055–3071
Muggeo VM (2008) Segmented: an R package to fit regression models with broken-line relationships. R News 8:20–25
R Core Team (2021) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna
Rehage JS, Santos RO, Kroloff EKN et al (2019) 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. Environ Biol Fish 102:285–298. https://doi.org/10.1007/s10641-018-0831-2
Richards LJ, Schnute JT (1986) An experimental and statistical approach to the question: is CPUE an index of abundance? Can J Fish Aquat Sci 43:1214–1227. https://doi.org/10.1139/f86-151
Santos RO, Lirman D, Pittman SJ, Serafy JE (2018) Spatial patterns of seagrasses and salinity regimes interact to structure marine faunal assemblages in a subtropical bay. Mar Ecol Prog Ser 594:21–38
Santos RO, Rehage JS, Adams AJ et al (2017) Quantitative assessment of a data-limited recreational bonefish fishery using a time-series of fishing guides reports. PLoS ONE 12:e0184776. https://doi.org/10.1371/journal.pone.0184776
Santos RO, Rehage JS, Kroloff EKN et al (2019) Combining data sources to elucidate spatial patterns in recreational catch and effort: fisheries-dependent data and local ecological knowledge applied to the South Florida bonefish fishery. Environ Biol Fish 102:299–317. https://doi.org/10.1007/s10641-018-0828-x
Santos RO, Varona G, Avila CL et al (2020) Implications of macroalgae blooms to the spatial structure of seagrass seascapes: the case of the *Anadyomene* spp. (Chlorophyta) bloom in Biscayne Bay, Florida. Mar Pollut Bull 150:110742. https://doi.org/10.1016/j.marpolbul.2019.110742
Smith ADM, Brown CJ, Bulman CM et al (2011) Impacts of fishing low–trophic level species on marine ecosystems. Science. https://doi.org/10.1126/science.1209395
Stallings C, Brower J, Heinlein Loch J, Mickle A (2014) Commercial trawling in seagrass beds: bycatch and long-term trends in effort of a major shrimp fishery. Mar Ecol Prog Ser 513:143–153. https://doi.org/10.3354/meps10960
Visser ME, Both C (2005) Shifts in phenology due to global climate change: the need for a yardstick. Proc R Soc B Biol Sci 272:2561–2569. https://doi.org/10.1098/rspb.2005.3356
Wachnicka A, Browder J, Jackson T et al (2020) Hurricane Irma's impact on water quality and phytoplankton communities in Biscayne Bay (Florida, USA). Estuaries Coasts 43:1217–1234. https://doi.org/10.1007/s12237-019-00592-4
Zink IC (2017) Nearshore salinity and juvenile pink shrimp (*Farfantepenaeus duorarum*): Integrating field observations, laboratory trials, and habitat suitability simulations. Dissertation, University of Miami
Zink IC, Browder JA, Lirman D, Serafy JE (2018) Pink shrimp *Farfantepenaeus duorarum* spatiotemporal abundance trends along an urban, subtropical shoreline slated for restoration. PLoS ONE 13:e0198539. https://doi.org/10.1371/journal.pone.0198539

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.