



A review of the potential impacts of commercial inshore pink shrimp fisheries on the recreational flats fishery in Biscayne Bay, FL, USA

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Abstract The recreational flats fishery (bonefish, tarpon, and permit) in South Florida is economically and culturally important and has declined recently for unknown reasons. Biscayne Bay is a shallow subtropical lagoon system with a flats fishery bordered by a large urban center. The Bay also supports commercial fisheries, including the pink shrimp bait and food fisheries. These two shrimp fisheries represent Biscayne Bay's most valuable fisheries, but how these fisheries interact with the recreational flats fishery is relatively unknown. We conducted a literature review to identify the potential direct and indirect effects of the two shrimp fisheries on the recreational flats fishery in the

Bay. Our review found that there are likely minimal impacts of the Biscayne Bay pink shrimp fisheries on the flats fishery in Biscayne Bay since (a) the species are not caught by shrimping gear, (b) the shrimp fishery removes less than 10% of the Bay's shrimp population, and (c) damage to seagrass is minimal (but hardbottom is damaged). Yet, the potential for indirect prey removal cannot be ruled out and requires quantification with additional diet data, food web, and mass balance models.

Keywords Bonefish · Tarpon · Permit · Roller-frame · Wingnet · Bycatch

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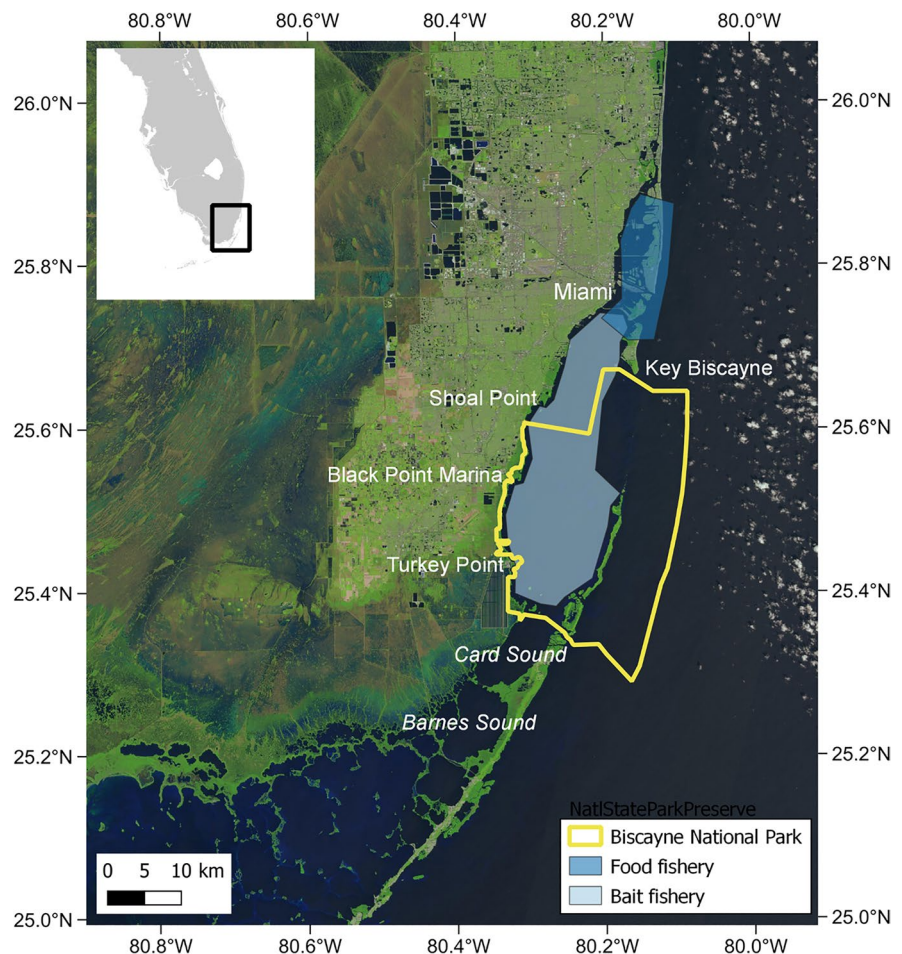
Introduction

The complex habitat mosaic of mangrove, seagrass, sand, coral reef, mud bottom, hardbottom, and benthic algae that comprise shallow tropical and subtropical coastal marine waters is collectively referred to as flats. These flats serve as essential habitat for many organisms (Rosenberg et al. 2000), including important recreational fishery species such as bonefish (*Albula vulpes*), tarpon (*Megalops atlanticus*), and permit (*Trachinotus falcatus*) (Adams and Cooke 2015; Adams et al. 2019). In South Florida (USA), the recreational flats fishery is of high economic and cultural importance (Fedler 2013), but recent studies have highlighted declines in this fishery in both catches and effort (Santos et al. 2017, 2019; Kroloff et al. 2019; Rehage et al. 2019; Boucek et al. 2022). While the exact reason is unknown, local ecological knowledge from key informant interviews of anglers

suggests the decline could be related to climate, water quality, food availability, or habitat loss (Kroloff et al. 2019).

Biscayne Bay is a large (1110 km²), shallow (depths generally < 3 m), subtropical lagoon system located downstream of the Florida Everglades and is surrounded by the city of Miami metropolitan area (population ~2.7 million) and multiple protected areas that preserve natural shorelines (Fig. 1). Thus, Biscayne Bay is heterogeneous in urbanization and habitat distribution with distinct gradients of natural and anthropogenic stressors (Santos et al. 2011, 2015, 2018; Lirman et al. 2014). Its western shoreline extends approximately 56 km from north to south. The entire Bay and adjacent embayments (Card and Barnes Sounds; Fig. 1) fall under a federal (Biscayne National Park, Florida Keys National Marine Sanctuary) or state (Biscayne Bay Aquatic Preserve) ecologically protected status. Where coastal

Fig. 1 Map of Biscayne Bay and general location of the pink shrimp bait and food fisheries. The spatial extent of the fishing grounds for the bait fishery is adapted from maps drawn by commercial bait shrimpers of areas targeted from Ault et al. (1997). The spatial extent of the fishing grounds for the food fishery is adapted from interviews conducted in an ethnographic study of commercial wingnet shrimpers (EDAW Inc. 2006)



urban development is low, its shorelines consist of a mangrove-seagrass ecotone punctuated by natural tidal creeks, artificial channels, and freshwater canals (Serafy et al. 2007). The natural hydrology of the Biscayne Bay watershed was modified with the construction of the Central and Southern Florida Project water-drainage system completed in the 1960s, and these changes resulted in substantial changes to the Bay's salinity regimes (Browder and Ogden 1999; Browder et al. 2005). Despite the immense hydrologic modification and urbanization, Biscayne Bay supports a lucrative recreational flats fishery (Fedler 2013). For example, the bonefish flats fishery in Biscayne Bay is perceived as being of higher quality (both in number and size of bonefish) by anglers compared to Florida Bay or the Florida Keys (Rehage et al. 2019). Despite a higher perception relative to other regions in South Florida, populations of bonefish in Biscayne Bay, like those throughout South Florida, have been in decline since the 1980s (Santos et al. 2017, 2019; Rehage et al. 2019). However, recent data points to a potential recovery of the bonefish population (Boucek et al. 2022).

One potential decline of the Biscayne Bay flats fishery populations is interactions with commercial fisheries within the Bay (Kelleher 2005). Biscayne Bay supports multiple commercial fisheries including two commercial pink shrimp (*Farfantepenaeus duorarum*) fisheries: (1) the live bait shrimp fishery that supports recreational fishing and (2) the food shrimp fishery for direct human consumption. Together these two commercial shrimp fisheries in Biscayne Bay represent the Bay's most important commercial fishery product (Johnson et al. 2012). Pink shrimp have high ecological importance as a major prey item and help support many commercial and recreational fishery species within the bay (e.g., bonefish, tarpon, permit) or that use Biscayne Bay as nursery habitat (e.g., reef fishes) before moving offshore as adults (Crabtree et al. 1998; Hammerschlag et al. 2010). Therefore, the two pink shrimp fisheries have the potential to interact both directly and indirectly with other fishery species (including the recreational flats fishery) in Biscayne Bay.

Pink shrimp, like other penaeid shrimp species, support lucrative commercial fisheries in the USA, and within the past decade, Florida pink shrimp landings can be as high as 12.6 million pounds and can value as high as 24.1 million USD (Zink 2017). Most

US commercial landings originate from Florida, especially from the Tortugas Grounds, northwest of Key West on the southwestern Florida Gulf shelf (Hart et al. 2012). A portion of the Florida landings come from the Biscayne Bay area. The portion of overall landings in Florida can be as high as 20% of the bait fishery and 11% of the food fishery depending on the year (Rezek et al. 2022). The Biscayne Bay pink shrimp population is thought to originate from the Tortugas Grounds, but a relationship between spawning grounds and the Biscayne Bay nursery has not been determined (Browder et al. 2005). Genetic evidence supports recruitment from the Tortugas Grounds population but also found evidence that another unknown spawning population (potentially from the Caribbean) contributes to the Biscayne Bay population (Timm et al. 2021).

Pink shrimp have a life cycle where juveniles use shallow nearshore waters as nursery habitats and migrate offshore as adults to spawn (Dall et al. 1990). The two commercial fisheries in Biscayne Bay take advantage of the life cycle of pink shrimp, targeting shrimp at different life stages. The pink shrimp bait fishery in Biscayne Bay supplies live shrimp to be used as bait for recreational fisheries around Biscayne Bay and in the Keys (Tabb 1958; Tabb and Kenny 1969; Berkeley et al. 1985; Ault et al. 1997). Operating year-round, the bait fishery is based on a quota system where dealers place orders to be filled, and landings are influenced by seasonal demands from tourism and levels of recreational fishing (Ault et al. 1997; Johnson et al. 2012). Shrimpers target seagrass beds in shallow (1–2 m) waters at night using roller-frame trawls that are designed to minimize damage to areas with seagrass cover (Ault et al. 1997). The majority of the catch is composed of juveniles and subadults between 10 and 22 mm carapace length (Johnson et al. 2012). The Biscayne Bay pink shrimp food fishery operates differently than the pink shrimp bait fishery. Shrimpers use vessels with wingnet gear and mainly sell to wholesale fish houses that ship pink shrimp to markets around the country (EDAW Inc. 2003). Wingnets are a gear that consists of two dip nets that are lowered into the upper portion of the water column on each side of the vessel and are typically limited to areas with water depths > 1.2–1.8 m. Shrimpers target areas where larger juvenile and subadult shrimp (carapace length ≥ 19 mm) aggregate in the upper water column with strong currents,

such as passes, channels, canals, and bridges, at night as they emigrate from Biscayne Bay (Criales et al. 2000; Johnson et al. 2012). Since 1999, the food fishery near Biscayne Bay has had an open season, currently between November 1 and May 31 (Johnson et al. 2012). Because of the differences in habitats targeted, the bait fishery operates mostly within Biscayne National Park, while the food fishery operates outside the park (Fig. 1).

The combination of the bait and food fisheries makes pink shrimp the most valuable commercial fisheries product in Biscayne Bay (Johnson et al. 2012), but other economically important fisheries (e.g., recreational flats fishery) exist within the Bay (Santos et al. 2017, 2019). Because of bycatch and habitat destruction caused by the gear types used, shrimp fisheries are generally condemned for their negative environmental impacts. Concern over the ecological impacts have been voiced since the onset of Biscayne Bay inshore pink shrimp live bait fisheries (Higman 1952; Tabb 1958; Berkeley et al. 1985). Here we conducted a literature review to identify and summarize previously reported and potential direct (e.g., bycatch) and indirect (e.g., habitat) effects of Biscayne Bay pink shrimp fisheries on the recreational flats fishery.

Methods

We performed a systematic literature search to acquire and synthesize information on the potential impacts of pink shrimp fisheries on recreational flats fishery in Biscayne Bay. To gather published literature, we conducted a key term search using three categories of key terms (one related to location, one related to pink shrimp fishery, and one related to ecological impacts) in Web of Science. The location terms were “Biscayne Bay” OR “Florida” OR “seagrass” OR “SAV,” the pink shrimp fishery terms were “pink shrimp” OR “roller-frame” OR “wingnet” OR “commercial trawling,” and the ecological impact terms were “bycatch” OR “habitat destruction” OR “habitat degradation” OR “disturbance.” Each search contained one key term from each category (e.g., searched “Biscayne Bay” AND “pink shrimp” AND “bycatch”), and all combinations of the three categories were used ($n = 60$ total searches). We supplemented the literature sources found on Web of Science by conducting

searches on Google Scholar with the same key terms, searching the first five pages of results. In addition to the Web of Science and Google Scholar searches, we searched the University of Miami RSMAS library Biscayne Bay Collection for federal reports and gray literature. Other sources were included from the authors’ personal libraries.

Results and discussion

Our key term search on Web of Science yielded 41 peer-reviewed sources (Table S1). With the addition of the Google Scholar and University of Miami RSMAS library Biscayne Bay Collection, a total of 99 sources were identified. Of those sources, 79 were peer-reviewed journals, 11 were from reports submitted to federal agencies, 4 were reports submitted to state agencies, 2 were United Nations FAO reports, 1 was a book chapter, and 2 were dissertations (Table S1).

Impacts of Biscayne Bay pink shrimp bait fishery

Bycatch

Roller-frame trawls are the fishing gear used in the Biscayne Bay bait fishery. Like other trawls, roller-frames are nondiscriminatory in what species are captured when they are deployed. Compared to otter trawls (another type of gear used in seagrass beds), roller-frames are much more effective at shrimp capture in seagrass habitats, but roller-frames are also effective at capturing other fishery-targeted species (Stallings et al. 2014b). One study that examined bycatch in multiple estuaries on the northwest coast of Florida found a very large bycatch rate, between 74 and 93% of the total abundance of trawls were from species other than pink shrimp, although bycatch rates differed by season and trawling location (Stallings et al. 2014a). Within Biscayne Bay, reported bycatch rates were lower but still significant (Tabb 1958; Berkeley et al. 1985; Ault et al. 2001; Crawford et al. 2011). Crawford et al. (2011) found that, based on weight, pink shrimp comprised 26%, finfish comprised 18%, and seagrass comprised 56% of the catch of control nets (animal bycatch rate = 41%). Other studies reported even lower values, with a bycatch rate of 24% of total catch abundance (Ault

et al. 2001), and bycatch rate of 15% of the total catch abundance for economically important species other than pink shrimp (total bycatch rate is likely higher for all taxa; Berkeley et al. 1985).

The bycatch of commercial and recreational fisheries species within pink shrimp roller-frame trawls has a direct impact on those populations, and the magnitude of this impact is species specific. Bycatch of fisheries species is typically limited to juveniles that use seagrass habitats as nurseries (Berkeley et al. 1985; Meyer et al. 1999; Stallings et al. 2014a). Excluder bars attached to roller-frames are intended to reduce bycatch and the amount of seagrass blades and algae collected (Tabb and Kenny 1969; Ault et al. 1997), and Stallings et al. (2014b) suggested that excluder bars may explain the lower amount of larger fauna collected by roller-frame trawls relative to otter trawls. Survivability of juveniles caught in trawls is species-specific, with some species (e.g., spotted seatrout *Cynoscion nebulosus*) with very high mortality (Stallings et al. 2014a). Also, having high survival related to trawl capture does not always equate to a successful release because fish returning to the water are susceptible to predation, and predatory species (e.g., dolphin, sea birds) are known to follow shrimp-ing boats (Meyer et al. 1999). Grunts and snappers were fisheries species with the highest bycatch rates, but other species included groupers, hogfish, and spiny lobster (Clark 1974; Berkeley et al. 1985; Ault et al. 2001; Serafy et al. 2007; Crawford et al. 2011). Studies of roller-frame bycatch in Biscayne Bay did not observe any of the recreational flats fishery species (i.e., bonefish, tarpon, permit) in their results (Table 1; Tabb 1958; Berkeley et al. 1985; Ault et al. 2001). Similarly, other roller-frame trawl bycatch studies from Florida also did not report these species in their collections (Meyer et al. 1999; Crawford et al. 2011; Stallings et al. 2014a, b). Although not studying pink shrimp bycatch specifically, Serafy et al. (1997) investigated Biscayne Bay fish assemblages using a roller-frame trawl and also did not report capturing recreational flats fishery species.

The pink shrimp bait fishery indirectly impacts commercial and recreational fisheries' populations in Biscayne Bay by removing food resources. Unlike bycatch of commercial and recreational fisheries' species that mainly affect juveniles, the removal of prey items impacts both juveniles and adults of fisheries populations that forage on resources from

Biscayne Bay. Because pink shrimp in Biscayne Bay are thought to originate from the Tortugas Grounds population, which is considered to not depend upon pink shrimp recruits from Biscayne Bay, it has been hypothesized that large fishing efforts in the Bay would likely not influence the overall population of pink shrimp the following year (Berkeley et al. 1985). Estimates of the proportion of the pink shrimp population in Biscayne Bay that is removed via the bait fishery range from 5.2% (Johnson et al. 2012) to 8–9 % (Campos and Berkeley 1986). However, food availability is a major driver of consumer populations, and because pink shrimp are important prey, large removal of the pink shrimp population via the bait fishery could have drastic effects on other fisheries species (Hiddink et al. 2011). Between 2018 and 2020, the average landings for the bait fishery in Biscayne Bay was 60,922.5 kg/year (Rezek et al. 2022).

Besides pink shrimp, other important prey items, such as pinfish (*Lagodon rhomboides*), gulf toadfish (*Opsanus beta*), and mojarra (*Eucinostomus* spp.) have some of the highest bycatch rates in roller-frame trawls throughout Florida (Higman 1952; Woodburn et al. 1957; Meyer et al. 1999; Crawford et al. 2011; Stallings et al. 2014a, b) and within Biscayne Bay (Clark 1974; Berkeley et al. 1985; Serafy et al. 1997; Ault et al. 2001; Crawford et al. 2011). Some of the earliest concerns regarding ecological impacts of bait shrimp fisheries included concerns regarding the removal of so-called trash fish that served as prey for important higher trophic level consumers (Woodburn et al. 1957). Berkeley et al. (1985), using fisheries observers aboard bait shrimp vessels, estimated that 4,768,197 pinfish are caught annually as bycatch from Biscayne Bay, which standardized to shrimp catch which is 131.06 pinfish per 1000 shrimp (Table 1). Although not as high, pinfish were the most common bycatch found in the fishery-independent survey using roller-frames in Ault et al. (2001).

These more recent studies provide higher-quality, quantitative assessments of the amount and composition of the bycatch associated with pink shrimp live bait fisheries than the more qualitative descriptions included in earlier investigations. Based on gut content analysis, many of the dietary items of bonefish, tarpon, and permit were main components of the catch of roller-frame trawls (Carr and Adams 1973; Crabtree et al. 1998; Jud et al. 2011). However,

Table 1 Catch of commercial and recreational fisheries species as well as important prey species from two studies using roller-frames in Biscayne Bay. Berkeley et al. (1985) used fisheries-dependent data to estimate the total annual catch of species and these species were standardized to shrimp catch (catch

per 1000 shrimp). Ault et al. (2001) used fisheries-independent data and was reported as the total number of individuals caught across all trawls. Data was standardized to catch per 1000 shrimp to allow comparison to Berkeley et al. (1985). Blank indicates not reported

Species		Berkeley et al. 1985		Ault et al. 2001	
		Estimated annual catch	Catch per 1000 shrimp	Number caught	Catch per 1000 shrimp
Pink shrimp	<i>Farfantepenaeus duorarum</i>	36,381,312	1000	103,896	1000
Pinfish	<i>Lagodon rhomboides</i>	4,768,197	131.06	8163	78.57
Gulf toadfish	<i>Opsanus beta</i>			4480	43.12
Silver jenny	<i>Eucinostomus gula</i>			3160	30.42
White grunt	<i>Haemulon plumierii</i>	586,823	16.13	3855	37.10
Bluestriped grunt	<i>Haemulon sciurus</i>	415,222	11.41	2350	22.62
Lane snapper	<i>Lutjanus synagris</i>	243,612	6.70	242	2.33
Gray snapper	<i>Lutjanus griseus</i>	26,964	0.74	594	5.72
Mutton snapper	<i>Lutjanus analis</i>	161,718	4.45	65	0.63
Spotfin mojarra	<i>Eucinostomus argenteus</i>			232	2.23
Spiny lobster	<i>Panulirus argus</i>	84,061	2.31	1	0.01
Blue crab	<i>Callinectes sapidus</i>	69,788	1.92	0	0
Hogfish	<i>Lachnolaimus maximus</i>	10,148	0.28	163	1.57
Banner goby	<i>Microgobius microlepis</i>			87	0.84
Spotted seatrout	<i>Cynoscion nebulosus</i>	45,997	1.26	34	0.33
Yellowtail snapper	<i>Ocyurus chrysurus</i>	5078	0.14	142	1.37
Inshore lizardfish	<i>Synodus foetens</i>			69	0.66
Sand perch	<i>Diplectrum formosum</i>	10,788	0.30	94	0.90
Rainwater killifish	<i>Lucania parva</i>			61	0.59
French grunt	<i>Haemulon flavolineatum</i>	10,788	0.30	76	0.73
Sailor's choice	<i>Haemulon parra</i>	13,003	0.36	61	0.59
Tomtate	<i>Haemulon aurolineatum</i>	5710	0.16	73	0.70
Grass porgy	<i>Calamus arctifrons</i>	8245	0.23	65	0.63
Pigfish	<i>Orthopristis chrysoptera</i>	2855	0.08	57	0.55
Sheepshead porgy	<i>Calamus penna</i>	2855	0.08	3	0.03
Gulf flounder	<i>Paralichthys albigutta</i>	2224	0.06	4	0.04
Stone crab	<i>Menippe mercenaria</i>	2855	0.08	0	0
Atlantic spadefish	<i>Chaetodipterus faber</i>			3	0.03
Yellow jack	<i>Caranx bartholomaei</i>	1903	0.05	0	0
Gray triggerfish	<i>Balistes capricus</i>			2	0.02
Great barracuda	<i>Sphyraena barracuda</i>			2	0.02
Ocean triggerfish	<i>Cantherhines sufflamen</i>			2	0.02
Bar jack	<i>Caranx ruber</i>	952	0.03	0	0
Nassau grouper	<i>Epinephelus striatus</i>	952	0.03	0	0
Gag grouper	<i>Mycteroperca microlepis</i>	632	0.02	0	0

further study would be needed to fully integrate the ecological impacts of bycatch removals related to the fishery. There are examples of studies that have used

diet and food-web analysis paired with mass-balanced dynamic models to assess the ecological consequences of prey removal on the stock or abundance

of fish populations (Christensen and Walters 2004; de Mutsert et al. 2012; Chagaris et al. 2015; Smith et al. 2020). Similar approaches could be adapted to assess the trophic effects of the removal of pink shrimp, and associated bycatch, by the pink shrimp live bait fishery in Biscayne Bay.

Habitat degradation

Roller-frame trawls are the most common gear type used in the pink shrimp bait fishery throughout Florida. Although similar shrimp fisheries exist throughout the southeast, roller-frames seem to be exclusively used in Florida, with otter trawls a common gear type in other locations (Crawford et al. 2011). Otter trawls (and most other trawl gears) drag across the bottom of the sea floor and can cause widespread damage, especially in seagrass habitats (Barnette 2001). Roller-frame trawls are designed to roll across the sea floor, and this design protects against most of the scraping damage caused by otter trawls (Tabb 1958; Berkeley et al. 1985; Ault et al. 1997; Barnette 1999, 2001). An analysis of the effects of roller-frames on the seagrass *Thalassia testudinum* in Tampa Bay found no differences in seagrass beds trawled compared to those not trawled for mean seagrass shoot density, number of blades per shoot, longest blade length per shoot, total blade length per shoot, or above- and below-ground biomass (Meyer et al. 1999). Ault et al. (1997) found similar results with seagrass beds showing little damage regardless of the number of times trawled. These findings are supported by Berkeley et al. (1985), which concluded that since each fished area of Biscayne Bay is trawled about four times over the course of a year, the lack of bay-wide declines in seagrass indicate roller-frame trawls are not destructive to seagrass habitats. Roller-frames do capture seagrass in trawls (Crawford et al. 2011), but this material is likely from seagrass that is already damaged, unattached, or leaves ready to detach, with little long-term damage to seagrass beds (Higman 1952; Woodburn et al. 1957; Tabb 1958).

Although roller-frames display little damage to the seagrass habitats they primarily target, this is not the case for hard bottom habitats, another key habitat type within Biscayne Bay (Ault et al. 1997; Barnette 2001). Tilmant (1979) found that roller-frame trawls turned over or crushed 80% of *Porites porites* and *Solenastrea hyades* corals and damaged over 50%

of sponges and 38% of gorgonians. This study also found damage to macroalgae, such as *Halimeda* and *Sargassum* (Tilmant 1979). After 11 months, damage to benthic organisms in hard bottom habitats persisted, but signs of recovery were evident (Tilmant 1979). Ault et al. (1997) found similar results showing damage to many organisms in hard bottom habitats. Interestingly, damage to hard bottom organisms was not linear with subsequent trawling events, displaying diminishing damage with increased trawling, and displaying a plateaued response in the amount of damage of sponges and soft corals (Ault et al. 1997). However, bait shrimpers target seagrass habitats for trawling since abundances of pink shrimp are greater relative to hardbottom (Ault et al. 1997).

Impacts of Biscayne Bay pink shrimp food fishery

The majority of what is known about the Biscayne Bay food fishery comes from an ethnographic study from Biscayne National Park. This information comes from interviews of commercial shrimpers and describes the vessel and gear type used and the types of locations targeted (EDAW Inc. 2003). Johnson et al. (2012) describes the fisheries' trends from 1987 to 2005 for the Biscayne Bay food fishery, but this source only included catch of the targeted pink shrimp.

Bycatch

The wingnet gear used in the Biscayne Bay food fishery was reportedly invented by a Cuban expatriate in Miami around the mid-1970s (EDAW Inc. 2003). However, Tabb (1958) described the channel lift or wingnet as a specialized gear used during winter months to catch shrimp from Biscayne Bay surface waters as they moved through tidal cuts. Another early report of a similar gear was described by Higman (1952) as channel, or lift, nets that were deployed at right angles to the vessel while anchored into the current in channels or "cuts" of Florida Bay. Similar variations of the gear called "butterfly" nets were developed elsewhere around the southern United States during the 1950s (Perret et al. 1996; Bourgeois et al. 2016). Wingnet shrimpers target areas that aggregate shrimp in the water column, typically areas with strong current such as canals, bridges, and channels, as they emigrate from inshore areas (EDAW Inc.

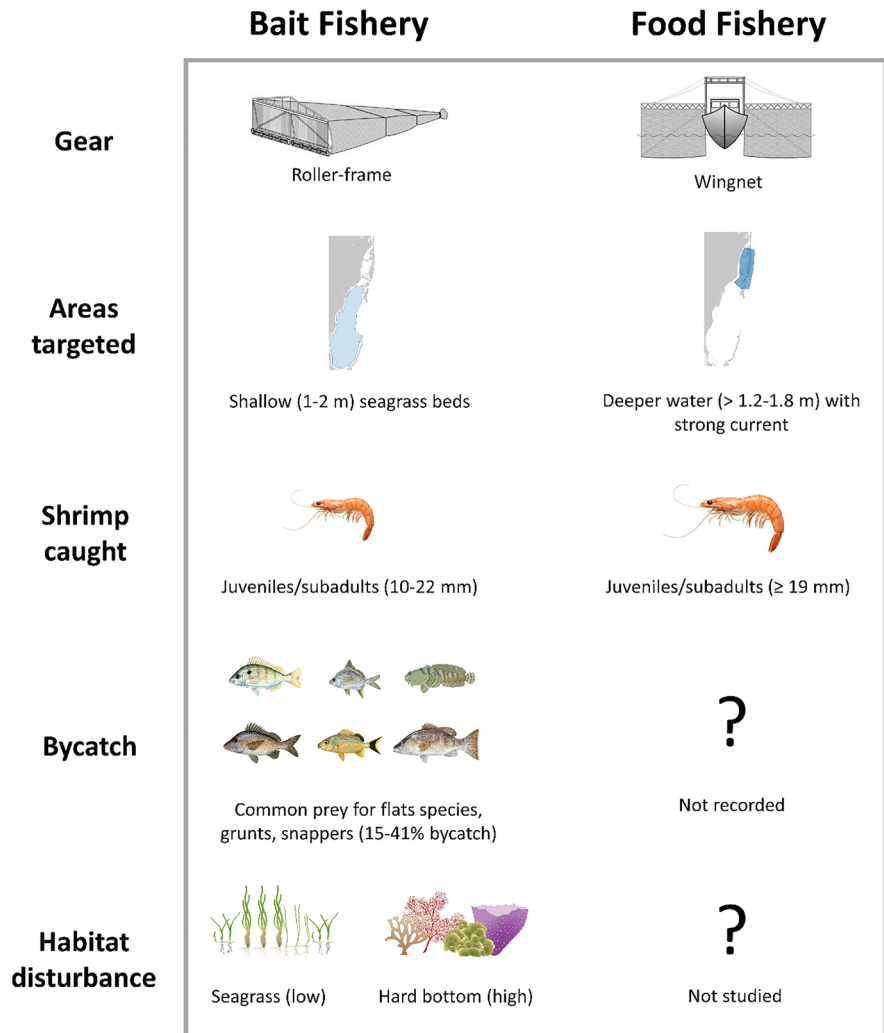
2003; Johnson et al. 2012). Where pink shrimp go after they leave Biscayne Bay is unknown (Costello and Allen 1966; Criales et al. 2000), but pink shrimp emigrating from estuaries are an important food source for many offshore fisheries species (Okey et al. 2004; Chagaris et al. 2015). If too heavily fished, the food fishery has the potential to limit this important food source which could have detrimental effects on the offshore fisheries populations. However, we hypothesize that the impact of this fishery, if any, is very limited due to the seasonality of the fishery and low fishing effort (mean of 104 trips/year between 2018 and 2020) currently occurring in Biscayne Bay (Rezek et al. 2022).

No studies could be identified that specifically addressed the bycatch associated with Biscayne Bay

wingnetting (Fig. 2). As summarized by Perret et al. (1996), finfish bycatch is lower in Louisiana butterfly nets relative to trawls (presumably otter, although the specific type was not reported), and bycatch mortality is reduced since butterfly nets are operated in well-oxygenated surface waters during the night when water and air temperatures are cooler (Adkins 1993). Wingnets would have the same limitations as other net type gears in which they are nonselective in what they capture. The bycatch in this fishery would likely differ compared to the bait fishery and would likely include pelagic species found in the water column (Thayer and Chester 1989; Coale et al. 1994; Warner et al. 2004).

Although different from the wingnets used in Biscayne Bay, skimmer trawls, common in the

Fig. 2 Conceptual diagram of findings of the literature review for the pink shrimp bait and food fisheries in Biscayne Bay. Image credit: NOAA and Integration and Application Network (Diana Kleine, Caroline Donovan, and Tracey Saxby, ian.umces.edu/media-library)



Louisiana and North Carolina shrimp fisheries, operate similarly as wingnets. Skimmer trawls are held by frames that push nets through the water column, but unlike wingnets that operate only in the upper portion of the water column, skimmer trawls operate through the entire water column and use a skid or ski attached to the bottom of the frame to allow it to slide over the benthos (Coale et al. 1994; Warner et al. 2004). One bycatch study using skimmer trawls in Apalachicola Bay found commercial and recreational fisheries species, such as spotted seatrout and gray snapper (*Lutjanus griesus*), included in the catch, and pelagic prey species were commonly caught (Warner et al. 2004). Additionally, wingnet gear could capture larvae of fisheries species or of potential prey that are recruiting into Biscayne Bay, but the magnitude of this impact would likely depend on the mesh size of the wingnets (Watson and McVea 1977; Colton et al. 1980).

Habitat degradation

Because wingnets target shrimp in the water column, there is likely little impact on the benthic habitat, unlike other gear types that drag or roll across the seafloor to catch pink shrimp (Tabb 1958). Our literature searches did not identify any studies that directly assessed potential habitat damage caused by wingnets. However, in agreement with Tabb's (1958) assessment, Barnette (1999, 2001) concluded that wingnets (or, more specifically, butterfly nets) would have negligible impact on mud, sand, and SAV habitats.

One other potential impact of the pink shrimp food fishery on other fisheries is interactions with recreational fishermen. Wingnet shrimpers target areas of aggregations of shrimp, but adult gamefish, such as tarpon, also use these areas to feed, making them target areas for fishermen (Ault et al. 2007). The presence of wingnet activity would likely reduce the quality of the recreational fishing habitat. Evidence of negative interactions between recreational fishermen and wingnet shrimpers around Biscayne Bay can be found on fishing forums (e.g., <https://forums.floridasportsman.com/discussion/237896/shrimping-report-miami-area>).

Conclusions

Concern over the ecological impacts, including destruction of benthic habitats and the high levels of bycatch, have been voiced since the onset of Biscayne Bay inshore pink shrimp fisheries (Higman 1952; Tabb 1958; Berkeley et al. 1985). The majority of Biscayne Bay pink shrimp fishery studies have focused on the bait fishery and gear types used within that fishery. Bonefish, tarpon, or permit were not listed as a species caught within roller-frame trawls in any of the studies we reviewed that reported bycatch information, whether they occurred in Biscayne Bay or elsewhere in Florida. Key prey items (including pink shrimp) of recreational flats fishery species were the most common species caught in the roller-frame trawls. However, the proportion removed from the estimated total Biscayne Bay pink shrimp population was low and likely also low for other prey species in the bycatch. Roller-frame trawls have low impact on seagrass habitats, but caused habitat damage to benthic, sessile invertebrates. What is known about the food fishery in Biscayne Bay comes from two studies, both of which reported on the economics of the fishery and did not consider ecological impacts. More studies on the bycatch and habitat degradation caused by wingnet gear are needed to understand the Biscayne Bay pink shrimp food fishery's ecological impact on the recreational flats fishery.

The populations of recreational flats fishery species in Biscayne Bay have been in decline since the 1980s, with the exact cause unknown (Kroloff et al. 2019). Based on our literature review, there is likely low impact of the Biscayne Bay pink shrimp fisheries on the decline of recreational flats fishery in Biscayne Bay. This coincides with other studies that found no relationship between landings, effort, or CPUE of either pink shrimp fisheries or the bonefish fishery in Biscayne Bay (Rezek et al. 2022). Bycatch of important prey items to flats fishery species could have an indirect effect on this fishery through reduction of food resources. However, estimates of proportion of prey removed from fishing are low, and this proportion is likely declining due to reduced effort of the pink shrimp fisheries (Rezek et al. 2022). Nevertheless, new systematic and quantitative studies (e.g., food web mass balance models) on Biscayne Bay's pink shrimp fisheries are still needed to have a better understanding on the population trends of this

species, the consequences of pink shrimp fishing on ecosystem trophic dynamics and Bay-wide productivity, and to better understand the socioeconomic conflict between different recreational fisheries and conservation strategies currently considered for Biscayne National Park.

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Declarations

Ethics approval No animals were harmed during this study.

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, 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>
- Adkins G (1993) A comprehensive assessment of bycatch in the Louisiana shrimp fishery. Marine Fisheries Division, Louisiana Department of Wildlife and Fisheries Technical Bulletin, p 71
- 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, p 80
- 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, p 165
- Ault JS, Humston R, Larkin MF et al (2007) Population dynamics and resource ecology of Atlantic tarpon and bonefish. In: Ault JS (ed) *Biology and management of the world tarpon and bonefish fisheries*. CRC Press Boca Raton, FL, p 217
- Barnette MC (1999) Gulf of Mexico fishing gear and their potential impacts on essential fish habitat. NOAA Technical Memorandum NMFS-SEFC-432, p 27
- Barnette MC (2001) A review of the fishing gear utilized within the Southeast Region and their potential impacts on essential fish habitat. NOAA Technical Memorandum NMFS-SEFSC-449, p 66
- 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 JS, Castillo NA et al (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>
- Bourgeois M, Chapiesky K, Landry L et al (2016) Louisiana shrimp fishery management plan. Louisiana Department of Wildlife and Fisheries, Office of Fisheries, p 158
- Browder JA, Alleman R, Markley S et al (2005) Biscayne Bay conceptual ecological model. *Wetlands* 25:854–869. [https://doi.org/10.1672/0277-5212\(2005\)025\[0854:BBCEM\]2.0.CO;2](https://doi.org/10.1672/0277-5212(2005)025[0854:BBCEM]2.0.CO;2)
- Browder JA, Ogden JC (1999) The natural South Florida system II: predrainage ecology. *Urban Ecosystems* 3:245–277
- Campos WL, Berkeley SA (1986) Impact of the commercial fishery on the population of bait shrimp (*Penaeus* spp.) in Biscayne Bay, 1986. NOAA Technical Memorandum NOS NCCOS CCMA 165, p 34
- Carr WES, Adams CA (1973) Food habits of juvenile marine fishes occupying seagrass beds in the estuarine zone near Crystal River, Florida. *Trans Am Fisheries Soc* 102:511–540. [https://doi.org/10.1577/1548-8659\(1973\)102%3c511:FHOJMF%3e2.0.CO;2](https://doi.org/10.1577/1548-8659(1973)102%3c511:FHOJMF%3e2.0.CO;2)
- Chagaris DD, Mahmoudi B, Walters CJ, Allen MS (2015) Simulating the trophic impacts of fishery policy options on the West Florida Shelf using Ecopath with Ecosim. *Marine Coastal Fish* 7:44–58. <https://doi.org/10.1080/19425120.2014.966216>
- Christensen V, Walters CJ (2004) Ecopath with Ecosim: methods, capabilities and limitations. *Ecol Model* 172:109–139. <https://doi.org/10.1016/J.ECOLMODEL.2003.09.003>
- Clark SH (1974) A study of variation in trawl data collected in Everglades National Park, Florida. *Trans Am Fish Soc* 103:777–785. [https://doi.org/10.1577/1548-8659\(1974\)103%3c777:ASOVIT%3e2.0.CO;2](https://doi.org/10.1577/1548-8659(1974)103%3c777:ASOVIT%3e2.0.CO;2)
- Coale JS, Rulifson RA, Murray JD, Hines R (1994) Comparisons of shrimp catch and bycatch between a skimmer trawl and an otter trawl in the North Carolina inshore shrimp fishery. *North Am J Fish Manage* 14:751–768
- Colton JB Jr, Green JR, Byron RR, Frisella JL (1980) Bongo net retention rates as effected by towing speed and mesh size. *Can J Fish Aquat Sci* 37:606–623. <https://doi.org/10.1139/f80-077>
- Costello T, Allen DM (1966) Migrations and geographic distribution of pink shrimp, *Penaeus duorarum*, of the Tortugas and Sanibel Grounds, Florida. *Fish Bull Fish Wildl Serv* 65:449–459
- Crabtree RE, Stevens C, Snodgrass D, Stengard FJ (1998) Feeding habits of bonefish, *Albula vulpes*, from the waters of the Florida Keys. *Fish bullet* 96:754–766

- Crawford CR, Steele P, McMillen-Jackson AL, Bert TM (2011) Effectiveness of bycatch-reduction devices in roller-frame trawls used in the Florida shrimp fishery. *Fish Res* 108:248–257
- Criales MM, Bello MJ, Yeung C (2000) Diversity and recruitment of penaeoid shrimps (Crustacea: Decapoda) at Bear Cut, Biscayne Bay, Florida, USA. *Bullet Marine 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, England, p 489
- de Mutsert K, Cowan JH Jr, Walters CJ (2012) Using Eco-path with Ecosim to explore nekton community response to freshwater diversion into a Louisiana estuary. *Marine Coastal Fish* 4:104–116. <https://doi.org/10.1080/19425120.2012.672366>
- EDAW Inc. (2003) Biscayne National Park Ethnographic Overview and Assessment. Final Report to Biscayne National Park, p 162
- Fedler A (2013) Economic impact of the Florida keys flats fishery. Bonefish & Tarpon Trust. <https://lkg.org/wp-content/uploads/2017/05/btt-keys-economic-report.pdf>
- 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>
- Hart RA, Nance JM, Primrose JA (2012) The U.S. Gulf of Mexico pink shrimp, *Farfantepenaeus duorarum*, fishery: 50 years of commercial catch statistics. *Marine Fish Rev* 74:1–6
- Hiddink JG, Johnson AF, Kingham R, Hinz H (2011) Could our fisheries be more productive? Indirect negative effects of bottom trawl fisheries on fish condition. *J Appl Ecol* 48:1441–1449. <https://doi.org/10.1111/j.1365-2664.2011.02036.x>
- Higman JB (1952) Preliminary investigation of the live bait shrimp fishery of Florida Bay and the Keys. University of Miami, Report to the Florida State Board of Conservation, Marine Laboratory
- Johnson DR, Browder JA, Brown-Eyo P, Robblee MB (2012) Biscayne Bay commercial pink shrimp, *Farfantepenaeus duorarum*, fisheries, 1986–2005. *Marine Fish Rev* 74:28–43
- Jud ZR, Layman CA, Shenker JM (2011) Diet of age-0 tarpon (*Megalops atlanticus*) in anthropogenically-modified and natural nursery habitats along the Indian River Lagoon, Florida. *Environ Biol Fish* 90:223–233. <https://doi.org/10.1007/s10641-010-9734-6>
- Kelleher K (2005) Discards in the world's marine fisheries: an update. Food and Agriculture Organization of the United Nations. FAO Fisheries Technical Paper. No 470
- 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>
- Lirman D, Thyberg T, Santos R et al (2014) SAV communities of western Biscayne Bay, Miami, Florida, USA: human and natural drivers of seagrass and macroalgae abundance and distribution along a continuous shoreline. *Estuaries Coasts* 37:1243–1255
- Meyer DL, Fonseca MS, Murphey PL et al (1999) Effects of live-bait shrimp trawling on seagrass beds and fish bycatch in Tampa Bay, Florida. *Fish Bull* 93:193–199
- Okey TA, Vargo GA, Mackinson S et al (2004) Simulating community effects of sea floor shading by plankton blooms over the West Florida Shelf. *Ecol Model* 172:339–359
- Perret W, Bowman P, Savoie L (1996) Bycatch in the Louisiana shrimp fishery. In: *Solving Bycatch: Considerations for Today and Tomorrow*. Sept 25–27, 1995, Seattle, Washington, USA. Alaska Sea Grant Program Report no. 96-03, pp 137–143
- 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>
- Rezek RJ, James WR, Bautista V et al (2022) Temporal trends of Biscayne Bay pink shrimp fisheries harvest, economic indicators, and potential interactions with South Florida recreational flats fisheries. *Environ Biol Fish*. <https://doi.org/10.1007/s10641-022-01314-9>
- Rosenberg A, Bigford TE, Leathery S et al (2000) Ecosystem approaches to fishery management through essential fish habitat. *Bullet Marine Sci* 66:535–542
- Santos R, Lirman D, Serafy J (2011) Quantifying freshwater-induced fragmentation of submerged aquatic vegetation communities using a multi-scale landscape ecology approach. *Mar Ecol Prog Ser* 427:233–246. <https://doi.org/10.3354/meps08996>
- Santos RO, Lirman D, Pittman SJ (2015) Long-term spatial dynamics in vegetated seascapes: fragmentation and habitat loss in a human-impacted subtropical lagoon. *Marine Ecol* 37:200–214. <https://doi.org/10.1111/maec.12259>
- 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. *Marine Ecol Progress Series* 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>
- Serafy J, Lindeman K, Hopkins T, Ault J (1997) Effects of freshwater canal discharge on fish assemblages in a subtropical bay: field and laboratory observations. *Mar Ecol Prog Ser* 160:161–172. <https://doi.org/10.3354/meps160161>
- Serafy JE, Valle M, Faunce CH, Luo J (2007) Species-specific patterns of fish abundance and size along a subtropical mangrove shoreline: an application of the delta approach. *Bullet Marine Sci* 80:609–624
- Smith M, Chagaris D, Paperno R et al (2020) Ecosystem structure and resilience of the Florida Bay Estuary: an original ecosystem model with implications for everglades restoration. *Mar Freshwater Res* 72:563–583. <https://doi.org/10.1071/MF20125>

- 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>
- Stallings CD, Brower JP, Heinlein Loch JM, Mickle A (2014) Catch comparison between otter and rollerframe trawls: implications for sampling in seagrass beds. *Fisheries Research* 155:177–184. <https://doi.org/10.1016/j.fishres.2014.03.002>
- Tabb D (1958) Report on the bait shrimp fishery of Biscayne Bay, Miami, Florida. Report to the Florida State Board of Conservation, p 17
- Tabb D, Kenny N (1969) A brief history of Florida's live bait shrimp fishery with description of fishing gear and methods. In: Mistakidis MN (ed) Proceedings of the world scientific conference on the biology and culture of shrimp and prawns. Fisheries Report: Experience Papers 3(57):1119–1134
- Thayer GW, Chester AJ (1989) Distribution and abundance of fishes among basin and channel habitats in Florida Bay. *Bulletin of Marine Science* 44:200–219
- Tilmant JT (1979) Observations on the impact of shrimp roller frame trawls operated over hardbottom communities in Biscayne Bay, Florida. National Park Service Report Series Number P-533, p 23
- Timm LE, Jackson TL, Browder JA, Bracken-Grissom HD (2021) Population genomics of the commercially important Gulf of Mexico pink shrimp *Farfantepenaeus duorarum* (Burkenroad, 1939) support models of juvenile transport around the Florida peninsula. *Front Ecol Evol* 9:445. <https://doi.org/10.3389/fevo.2021.659134>
- Warner DA, McMillen-Jackson AL, Bert TM, Crawford CR (2004) The efficiency of a bycatch reduction device used in skimmer trawls in the Florida shrimp fishery. *North Am J Fish Manage* 24:853–864
- Watson J, McVea C (1977) Development of a selective shrimp trawl for the southeastern United States penaeid shrimp fisheries. *Mar Fish Rev* 39:18–24
- Woodburn KD, Eldred B, Clark E et al (1957) The live bait shrimp industry of the west coast of Florida (Cedar Key to Naples). Florida State Board of Conservation Marine Laboratory Technical Series Number 21, p 33
- Zink IC (2017) Nearshore salinity and juvenile pink shrimp (*Farfantepenaeus duorarum*): integrating field observations, laboratory trials, and habitat suitability simulations. Dissertation, University of Miami. Available from: https://scholarlyrepository.miami.edu/cgi/viewcontent.cgi?article=3030&context=oa_dissertations

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