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MANAGEMENT BRIEF

Increasing the Selectivity of the Stone Crab *Menippe mercenaria* Trap by the Addition of a Cull Ring

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Abstract
The fishery for stone crab *Menippe mercenaria* in Florida is dominated by plastic traps that do not require a cull ring or device that limits retention of prerecruits and bycatch. An experiment was conducted to determine what size of cull ring would reduce the catch of prerecruit stone crabs and bycatch while maintaining legal catch. Catch compositions of crabs from unmodified plastic commercial stone crab traps and traps fitted with a 54.0-, 55.6-, or 57.2-mm cull ring were compared in the stone crab fishery across Florida's west coast. Traps outfitted with cull rings retained bigger crabs, less bycatch, and fewer prerecruit stone crabs and, for most cull ring sizes tested, yielded the same number of legal-size claws. Retention of prerecruit crabs in traps with cull rings varied among regions because of the sexual dimorphism in carapace length (males, 58.2 mm; females, 64.6 mm) observed when an original crusher claw has reached legal size (>70 mm). We recommend that a minimum size cull ring of 55.6-mm (2³⁄₁₆ in) be used in stone crab traps fished in state and federal waters off Florida.

The majority of North America's stone crab *Menippe mercenaria* harvest is landed in the eastern Gulf of Mexico (GOM) off the west coast of Florida (Muller et al. 2011; NMFS 2011). In 2016, the U.S. stone crab fishery produced 1,329 metric tons of crab claws with a value of US$28.7 million (NMFS 2016). Florida alone landed 1,307 metric tons of claws valued at $28.6 million, representing 98.3% of the U.S. total (Table 1).

The consistent high demand, limited supply, and high market value of stone crab claws have been the motivation for developing stone crab fisheries in other states and outside the USA. (Perry et al. 1984, 1995; Wenner and Stokes 1984; Horst and Bankston 1986; Bert and Hochberg 1992; Landry 1992), but in the northern GOM and the southeast Atlantic Bight, directed fisheries for stone crabs have not been established. In these regions the stone crab is an incidental catch in the wire traps of the blue crab *Callinectes sapidus* fishery (Perry et al. 1984; Wenner and Stokes 1984; Landry 1992; Page et al. 2013; SCDNR 2017), and the annual catch has remained near 22.7 metric tons since 2000 (NMFS 2011) and in 2016 represented 1.7% of U.S. landings (Table 1).

Federal promotion of regionally uniform fishery regulations (NMFS 2011) and Florida's domination of U.S. stone crab landings led to a shift in management. The Stone Crab Fisheries Management Plan in the Gulf of Mexico, in effect since 1979, was repealed in 2011, and management of the stone crab fishery in federal waters off Florida was transferred to the state of Florida (USOFR 2011). In state and federal waters off Florida, claws can be harvested from stone crabs caught in traps or by hand from October 15 through May 15. During this time, only claws >70 mm propodus length (PL) can be harvested, the harvest of claws from egg-bearing females is prohibited, and the crab must be released back to the water after the claw is removed (Florida Statutes Chapter 68B, Section 13). In states other than Florida, there are no regulatory guidelines for the use of stone crab traps, and regulations are inconsistent (Duermit et al. 2017).

Plastic stone crab traps introduced in the 1970s (GMFMC 1979) are now the dominant gear type used in the Florida stone crab fishery (Florida Fish and Wildlife Derelict Trap Retrieval Program, unpublished data). In Florida, a legal plastic trap must not exceed 610 × 610 × 610 mm, or a volume of 0.23 m^3. Each trap must have a vertically mounted entrance funnel that does not exceed 140 × 89 mm and an escape opening of 140 × 89 mm covered by a degradable slat made of cypress or untreated pine

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no thicker than 19 mm (Florida Statutes Chapter 68B, Section 13). The state of Florida allows more traps to be used than are needed to maintain the catch, resulting in the rapid harvest of 909 to 1,590 metric tons of stone crab claws each season (Muller et al. 2011). In 2002, the state of Florida implemented a trap-reduction plan to reduce overfishing by gradually decreasing the number of traps from 1.4 million to 600,000 (Florida Statutes Chapter 68B, Section 13). At the current rate of trap reduction, it will take until 2048 to reach this goal (Muller et al. 2011). During the 2016–2017 fishing season, 1.1 million stone crab trap tags were issued (Florida Fish and Wildlife Fisheries Information System 2017), but the proportion of traps actively used for fishing, their exact composition (plastic or wood), and loss rates are not documented. Refining trap selectivity may reduce the environmental and fishery impacts that are caused by the excessive number of traps.

Stone crab traps were designed to target and capture the largest stone crabs in the population (Bert 1985). Though these traps are intended to selectively catch legal-size stone crabs, the catch composition changes spatially and temporally and often includes sublegal stone crabs (prerecruits), bycatch of teleost fishes, and other crustaceans (Bender 1971; Bert et al. 1978, 1986, 2016; Savage and Sullivan 1978; Sullivan 1979; Wenner and Stokes 1984; Bert 1985; Wilber 1989, 1992; Ehrhardt et al. 1990; Bert and Hochberg 1992; Gerhart and Bert 2008; Crowley 2017). Crab trap modifications, such as cull rings, can allow prerecruit crabs and bycatch to escape (Uhlmann and Broadhurst 2015). The addition of cull rings to wire traps used in the U.S. fishery for the blue crab reduced prerecruit catch by 75–80%, reduced on-vessel culling time, reduced bycatch, and mitigated the impact of ghost fishing on prerecruit crabs (Guillory and Hein 1998; Guillory et al. 2004; Rudershausen and Turano 2009; Rudershausen and Hightower 2016). Unlike the blue crab fishery in Florida, the state's stone crab fishery is not required by law to install cull rings in plastic or wood traps, nor has their effect on the selectivity of a stone crab trap been published.

TABLE 1. U.S. stone crab landings in 2016. Commercial data from NMFS are based on calendar year, not fishing season, which varies by state. Value is in U.S. dollars. Source: NMFS 2016.

	Landings	
State or region	Metric tons	Value
Florida west coast	1,290	$28,105,776
Florida east coast	17	$493,008
South Carolina	15	$98,499
North Carolina	4	$21,596
Texas	2	$23,536
Louisiana	2	$5,519
Total	1,329	$28,747,934

The Florida stone crab catch is primarily composed of *M. mercenaria*, but in the northern GOM, can include the morphologically different Gulf stone crab *M. adina* and hybrids of these two related species (Bert et al. 1986; Williams and Felder 1986; Wilber 1992; Perry et al. 1995). While *M. adina*, *M. mercenaria*, and their hybrids differ morphologically, they have similar sexually dimorphic relationships between the claw PL and carapace width (CW) when an original (nonregenerated) crusher claw has reached 70 mm PL. The original crusher PL is used for comparison with carapace size in stone crabs because it is always the largest claw and the first claw to reach legal size, and stone crab growth rates may vary in crabs that are regenerating claws (Savage and Sullivan 1978). Regenerated claws have a broken stridulatory pattern on the inner surface of the propodus (Savage et al. 1975). Males of both species attain a legal claw PL of 70 mm at a smaller CW than do females (Table 2). Perry et al. (1995) compared the PL and CW measurements of *M. mercenaria* from Sullivan (1979) with those of *M. adina* from the north-central GOM and concluded with

TABLE 2. Stone crab carapace widths when original crusher PL is 70 mm.

	Carapace width (mm)			
Species	Male	Female	Location	Study
M. mercenaria	80	89	Florida (central)	Savage and Sullivan (1978)
	80	87	Florida (southwest)	Sullivan (1979)
	78	87	Florida (southwest)	Bert et al. (1986)
	78	88	Florida (central)	Gerhart and Bert (2008)
	83	92	South Carolina	Wenner and Stokes (1984)
	84	90	South Carolina	Caldwell (1992)
M. adina	80	90	Texas (central)	Landry (1992)
	81	93	Mississippi	Perry et al. (1995)

>95% confidence that both species produced a 70-mm PL original crusher at similar CWs. Therefore, cull ring sizes should affect both species similarly.

The ability of a crab to move through a cull ring is determined by its carapace length (CL) (Guillory and Hein 1998; Rudershausen and Turano 2006; Rudershausen and Hightower 2016). While the relationship between CW and original legal crusher PL in stone crabs is well established (Table 2) and indicates that males recruit to the fishery at a smaller CW than do females, a linear relationship between CL and original legal crusher PL has not been tested. A close relationship between CW and CL was documented in stone crabs in Tampa Bay, Florida (Savage and Sullivan 1978), so a relationship between CL and original legal crusher PL is probable but requires testing for the development of cull rings.

In 2015, the Florida Fish and Wildlife Conservation Commission's (FWC) Stone Crab Fishery Independent Monitoring Program (SCFIM) program began research to (1) estimate the CL at which stone crabs recruited to the fishery, (2) select three sizes of cull ring for testing, (3) test the effect of those ring sizes on the composition of stone crab catch and bycatch in plastic stone crab traps throughout Florida's west coast fishery. The goal of this research was to recommend a cull ring size that maintains legal catch of stone crabs while reducing the catch of prerecruits and bycatch.

METHODS

Study sites.— Four SCFIM locations—Cedar Key (29°4.1′N, 83°7.3′W), Tampa Bay (27°32.8′N, 82°43.3′W), Pavilion Key (25°39.7′N, 81°23.1′W), and Sawyer Key (24°47.0′N, 81°36.7′W)—were chosen for the collection of morphological data in April of 2016. These data were used to select cull ring sizes for testing in plastic stone crab traps during the 2016–2017 stone crab fishing season (October 15, 2016–May 15, 2017). The locations were chosen because they spanned the latitudinal distribution of the stone crab fishery along Florida's west coast.

Cull ring sizes.— A regression of male CL and the legal original crusher PL was made using data collected from 20 plastic stone crab traps deployed at each of the four SCFIM sites during April 2015. The results of the regression were subsequently used to approximate the CL at which male stone crabs recruit to the fishery and select ring sizes for testing. The mean CL measurement was rounded to the closest 1.6-mm (1⁄16 in) increment to correspond to the imperial units used in fishery regulations and stone crab trap construction. Cull rings were made in three sizes, in decreasing 1.6-mm (1⁄16 in) increments: 57.2 mm (2¼ in), 55.6 mm (2 3⁄16 in), and 54.0 mm (2⅛ in).

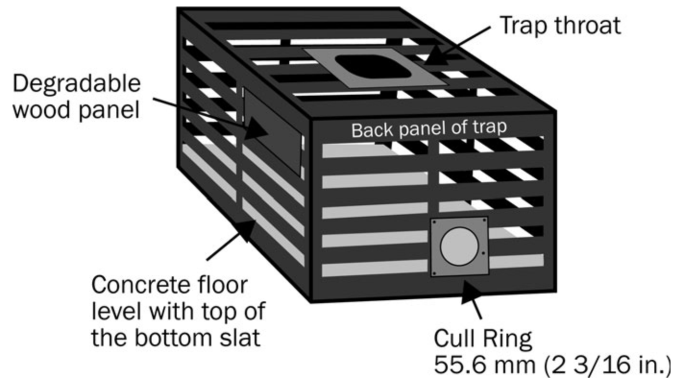

FIGURE 1. Cull ring mounted on the hinged side of a standard commercial trap, placed level with the top of the concrete bottom of the trap, and off-center relative to the center support slat.

Cull rings were constructed from square grade 6061 aluminum plates (102 mm long × 102 mm wide × 3.2 mm thick) to ensure that stone crabs could not deform the ring. A hole (54.0, 55.6, or 57.2 mm) was cut in the center of each plate by a precision machine shop. Cull rings were mounted on the inside of the hinged side of standard commercial plastic stone crab traps. A ring was placed level with the top of the concrete bottom of the trap, off center from the center support slat, and affixed to the plastic trap with four #8 stainless steel screws (Figure 1).

Cull ring studies.— At each study site we fished a string of 16 plastic stone crab traps for 213 d starting October 5, 2016, and ending May 2, 2017. Each string of traps contained four replicates of each trap type: (1) trap with no cull ring, (2) trap with a 54.0-mm cull ring, (3) trap with a 55.6-mm cull ring, (4) trap with a 57.2-mm cull ring. Traps were placed in a line at 100-m intervals in no designated order and were retrieved every 12–14 d. Traps were baited with approximately 0.75 kg of Striped Mullet *Mugil cephalus*, which has been the standard bait for SCFIM stone crab trap studies since 1988. When we retrieved a string of traps, we pulled each trap individually and collected all the stone crabs that had been caught in each trap. For each stone crab in a trap we recorded its sex, reproductive state, CW, CL, left and right PL, and claw type (original or regenerated, crusher or pincer). Additionally, for each trap we recorded the type and number of species of bycatch, and any missing traps were noted.

Analysis.— All analyses were conducted with SAS version 9.4 (SAS Institute, Cary, North Carolina). We used linear regression analysis (PROC REG) to determine the predicted upper and lower limits of the 95% CI for each crab's CL that corresponded to a legal original crusher PL of >70 mm for each sex and excluded egg-bearing females. Cull ring sizes were selected that would allow the passage of prerecruits while retaining crabs with legal claws. To test for differences in catch of crabs and bycatch among trap types we used generalized linear mixed models (PROC GLIMMIX). We used a negative binomial distribution with a log link because the data were discrete counts. Our unit of replication for these analyses was the string of traps; we summed catch across traps within a trap type at each string and estimated CPUE (catch per soak night) by including the number of soak nights as an offset in the model. We included trap type and location as well as their interaction as fixed effects. We included string as a random variable to account for the lack of independence between traps that were set together. We used a linear mixed model to test for differences in CL according to the fixed effects of trap type, sex, and location and their two-way interactions. We included trap type and string as random variables to account for the nonindependence between crabs caught in the same trap type and those caught in multiple trap types set together in a string. We used a Dunnett's adjustment to compare trap types (Dunnett 1980).

RESULTS

The relationship between CL and PL was found by collecting 754 stone crabs from the four study locations in April 2015. The sample of crabs was composed of 365 males and 389 females; the male : female (M:F) sex ratio was 0.9:1. A significant positive relationship was observed between original crusher PL and CL for males ($F_{1,\ 363}$ = 2200.8, P < 0.001) and for females ($F_{1,\ 387}$ = 1532.8, P < 0.001). The relationship for males is expressed as PL = 1.376·CL − 10.038 (r^2 = 0.86), and that for females is expressed as PL = 1.165·CL − 5.199 (r^2 = 0.80). For males, the CL at which the length of an original crusher PL would be at a legal length of 70 mm was predicted to be 58.2 mm (95% CI = 48.6–67.9), and for females, it was 64.6 mm (95% CI = 54.6–74.6).

Cull ring studies conducted across all four locations captured a total of 3,618 stone crabs having a M:F sex ratio of 0.6:1 (Table 3), along with 920 nontarget individuals (bycatch) comprising 44 species (Table 4). Overall, total bycatch was significantly lower in traps containing a cull ring than in traps without a cull ring ($F_{3,\ 120}$ = 22.04, P < 0.001), and the amount of bycatch differed across locations ($F_{9,\ 120}$ = 2.35, P = 0.018) (Figure 2). Cull rings reduced bycatch in all locations except Pavilion Key (Figure 2).

Overall, CL differed among trap types ($F_{3,\ 3,057}$ = 5.41, P = 0.001; Figure 3), among locations ($F_{3,\ 3,057}$ = 8.17, P < 0.001; Figure 3), and between sexes ($F_{1,\ 3,057}$ = 14.51, P < 0.001; Figure 4). In general, the CL of crabs from traps with cull rings was larger than that of crabs from the traps without cull rings, but this difference varied with location (Figure 3). We also found a significant interaction between location and trap type ($F_{9,\ 3,057}$ = 2.26, P = 0.014; Figure 3) and between sex and location ($F_{3,\ 3,057}$ = 7.87, P < 0.001; Figure 4). This interaction indicated that while females were, on average, larger (CL) than males, this difference varied with location (Figure 4). There was no interaction between sex and trap type ($F_{3,\ 3,057}$ = 0.67, P = 0.573).

Overall, legal claw CPUE differed with cull ring size ($F_{3,\ 118}$ = 4.56, P = 0.005), and an interaction was evident between trap type and location ($F_{9,\ 118}$ = 2.31, P = 0.020; Figure 5). In Sawyer Key, the trap with the 55.6-mm cull ring had a lower legal claw CPUE than did the traps without a cull ring (Figure 5). At no other location or cull-ring

TABLE 3. Summary of the statewide stone crab catch in Florida.

	Catch			
Trap type	Male (n)	Female (n)	M:F ratio	Bycatch (n)
No ring	419	655	0.6:1	569
54.0 mm	364	571	0.6:1	104
55.6 mm	294	545	0.5:1	139
57.2 mm	261	509	0.5:1	108
Total	1,338	2,280	0.6:1	920

TABLE 4. The top 20 nontarget species caught in stone crab traps during this study. CK = Cedar Key, TB = Tampa Bay, PK = Pavilion Key, SK = Sawyer Key.

	Location				
Species	CK	TB	PK	SK	Total
Hepatus epheliticus	4	398	20	4	426
Libinia emarginata	36	159	2		197
Neverita duplicate	34				34
Octopus vulgaris	26	3		1	30
Opsanus beta		13	15		28
Phyllonotus pomum	1		6	11	18
Pagurus sp.	5	4	1	8	18
Noetia ponderosa	15				15
Libinia dubia	13				13
Serranus subligarius	11				11
Callinectes sapidus	4	1	4		9
Lutjanus synagris	2	1	5		8
Paraclinus marmoratus	2		6		8
Calappa flammea		7			7
Haemulon plumierii	2		2	3	7
Dinocardium robustum	7				7
Fasciolaria sp.	7				7
Centropristis striata	6				6
Fulguropsis spirata	4		2		6
Balistes vetula				6	6

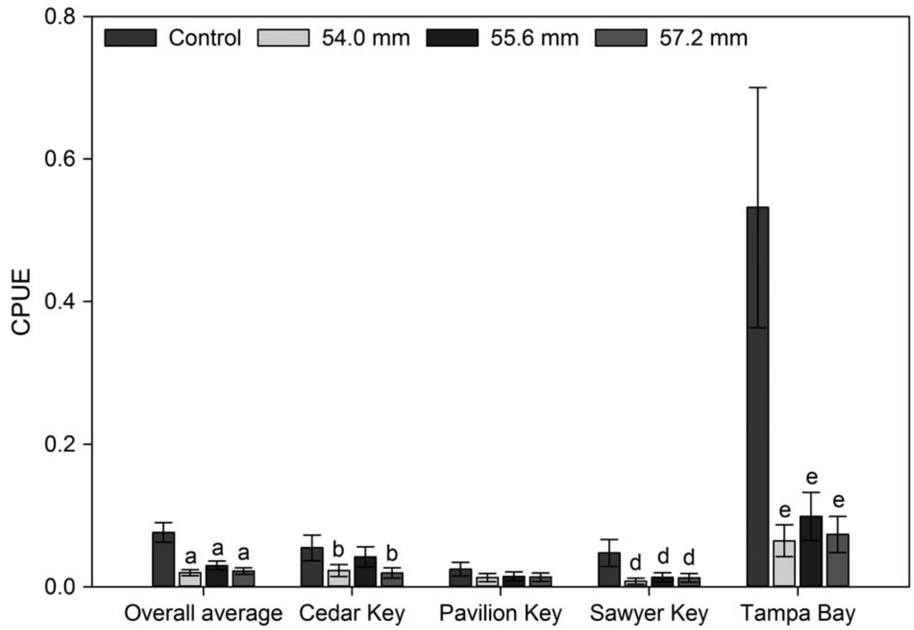

FIGURE 2. Total bycatch CPUE (catch per soak night) and 95% CIs for plastic stone crab traps without a cull ring and with 54.0-mm, 55.6-mm, and 57.2-mm cull rings. Within each location, catch of traps having cull rings that differ significantly from the catch of traps without a cull ring are denoted with a common letter (Dunnett's $P < 0.05$).

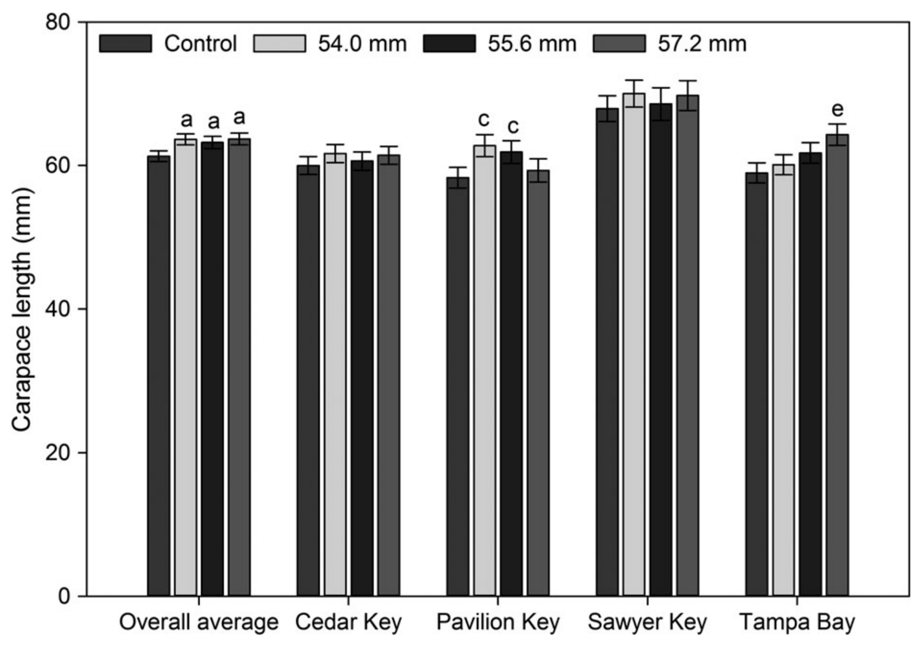

FIGURE 3. Carapace length (mm) (mean ± 95% CI) of stone crabs fished at several locations around Florida using plastic stone crab traps without a cull ring and with a 54.0-mm, 55.6-mm, and 57.2-mm cull ring. Within each location, catch of traps having cull rings that differ significantly from the catch of traps without a cull ring are denoted with a common letter (Dunnett's $P < 0.05$).

size was there a difference in legal claw CPUE between the traps with a cull ring and traps without a cull ring (Figure 5). Sublegal claw CPUE differed by trap type ($F_{3,\ 118} = 15.52$, $P < 0.001$); there was an interaction between trap type and location ($F_{9,\ 118} = 3.12$, $P = 0.002$; Figure 6). On average, sublegal claw CPUE was lower in traps with cull ring, but there were differences across locations (Figure 6).

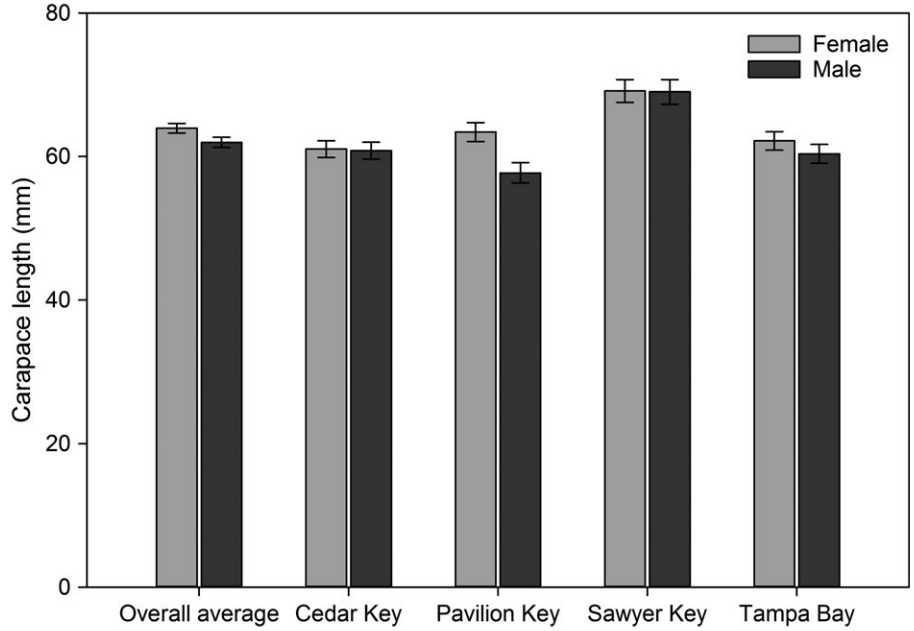

FIGURE 4. Carapace length (mm) and 95% CIs for female and male stone crabs, averaged across locations and at each of four locations in the state of Florida.

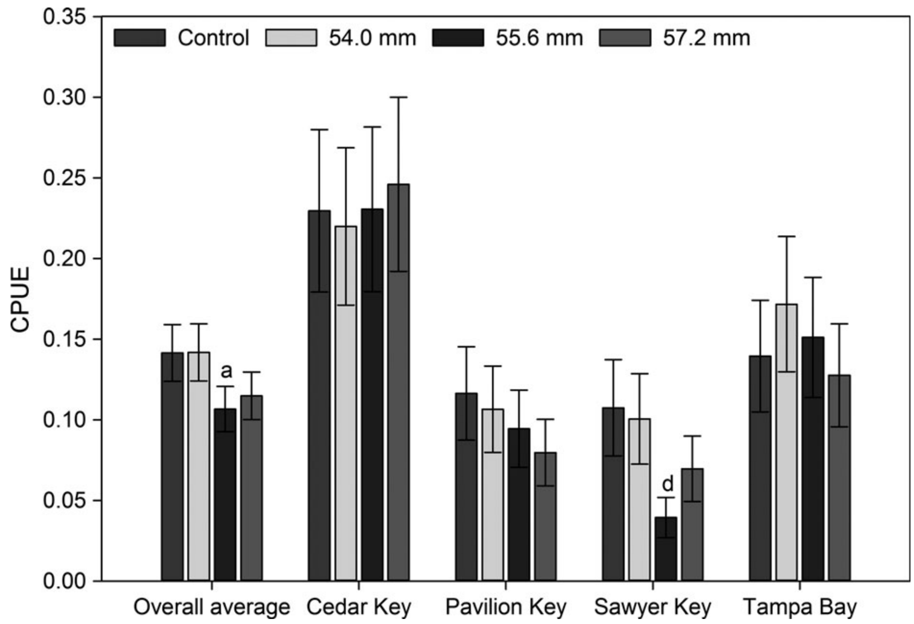

FIGURE 5. Legal-size claw CPUE (catch per soak night) and 95% CIs for plastic stone crab traps without a cull ring and with 54.0-mm, 55.6-mm, and 57.2-mm cull rings. Within each location, catch of traps having cull rings that differ significantly from the catch of traps without a cull ring are denoted with a common letter (Dunnett's $P < 0.05$).

DISCUSSION

This study found a sexually dimorphic, linear relationship between CL and original crusher PL for male and female stone crabs. This relationship, combined with the linear relationship between CW and CL (Savage and Sullivan 1978) and that between CW and original crusher PL (Table 2), indicates that both CL and CW are useful in estimating the carapace size at which stone crabs recruit to the fishery. We found that males recruited to the fishery at a smaller CL than did females (males CL, 58.2 mm; females

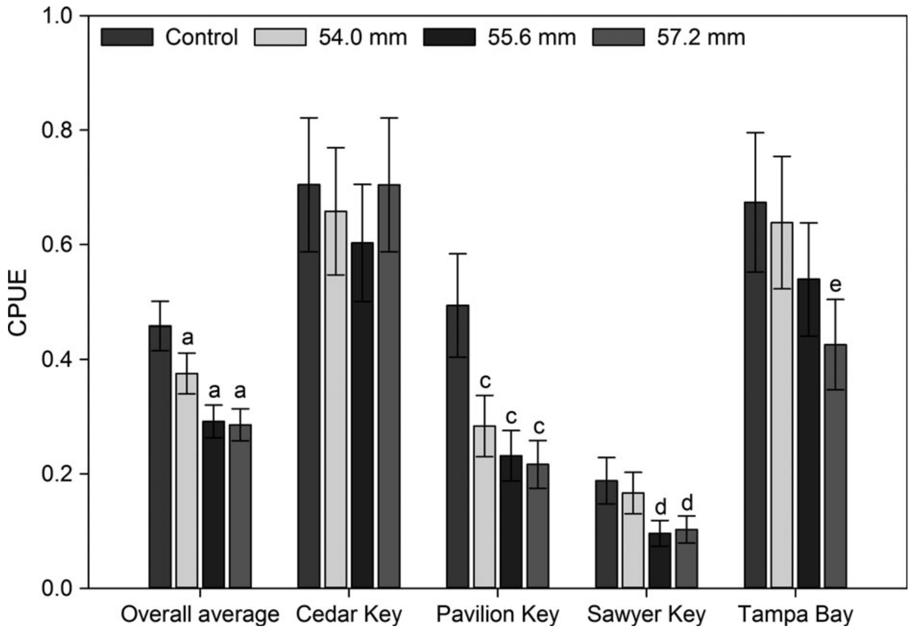

FIGURE 6. Sublegal-size claw CPUE (catch per soak night) and 95% CIs for plastic stone crab traps without a cull ring and with 54.0-mm, 55.6-mm, and 57.2-mm cull rings. Within each location, catch of traps having cull rings that differ significantly from the catch of traps without a cull ring are denoted with a common letter (Dunnett's $P < 0.05$).

CL, 64.6 mm). We used the male CL to select ring sizes for testing that would maximize the retention of stone crab recruits to the fishery and escapement of prerecruit crabs. The overall variability in the observed CL of stone crab recruits to the fishery is likely the greatest contributor to the differences in performance of cull rings tested. This finding is similar to that for other crustacean fisheries where cull rings are used (Guillory and Hein 1998; Rudershausen and Turano 2009; Broadhurst et al. 2014). However, other studies suggest, in addition to CL, that shell height may play a role in limiting the escapement of prerecruits (Brown 1982; Zhou and Shirley 1997; Rotherham et al. 2013; Broadhurst et al. 2014). Even with the variability inherent in stone crab allometry, our incorporation of cull rings only had negative effects on the CPUE of legal-size claws at Sawyer Key, where the 55.6-mm ring yielded a different CPUE. Cull rings reduced the catch of prerecruit stone crabs and bycatch in all locations.

Cull rings and escape gaps are one of the most common and effective devices used in decapod fisheries (Winger and Walsh 2007). These devices have been applied to existing traps in multiple crab fisheries, because they are a simple and cost-effective device that reduces the retention of prerecruits and bycatch, overall mortality, onboard culling time, and ghost fishing mortality, while increasing future legal CPUE (Guillory and Hein 1998; Rotherham et al. 2013; Broadhurst et al. 2014). The use of cull rings in crab traps is important in preventing exposure of prerecruits to the stress and mortality associated with containment in traps, onboard handling, and retention in actively fishing ghost traps (Guillory and Hein 1998; Guillory 2001; Uhlmann and Broadhurst 2015). In the stone crab fishery, containment of stone crabs in traps causes an estimated 12.8% mortality (Gandy et al. 2016), and an additional 23–100% mortality is induced by onboard culling, retention of crabs (boxing) for measurement, handling before release, and exposure to fluctuating air and water temperatures (Simonson and Hochberg 1986; Kronstadt et al. 2017). The mortality rates of actively fishing ghost traps are unknown but thought to be significant, because plastic stone crab traps are durable and can fish until the required biodegradable wood slat breaks free. Wood slats have been observed (n = 178 traps) retaining stone crabs in a trap for an average of 280 d and a range of 28–1,310 d (SCFIM, unpublished data). Retaining crabs in a trap for this length of time will likely lead to cannibalism, starvation, and disease. Thus, allowing prerecruit stone crabs to escape can directly benefit future stone crab stock abundance and fishery landings. Crowley (2017) estimated that spawning potential ratios increased 2% when mortality was decreased by using a 55.6-mm cull ring. Incorporating a cull ring into a stone crab trap is a simple and inexpensive management strategy that effectively releases prerecruits and bolsters the spawning population of stone crabs while having a negligible effect on the CPUE of legal claws.

The addition of cull rings (regardless of size) to stone crab traps reduced bycatch. Bycatch composition and distribution varied by location and contained no threatened or imperiled species. The release of nontarget species and prerecruits is instrumental in continued efforts to reduce the mortality associated with nonselective fishing gear, which accounts for 8–40% of fishing mortality worldwide (Kelleher 2005; Davies et al. 2009; Favaro et al. 2013). The 16 unmodified plastic stone crab traps used in our study during the 2016–2017 fishing season caught 569 nontarget individuals of other species and 616 prerecruit stone crabs. In the same season the state of Florida sold 1.1 million trap tags, but did not track the number of traps fished. Given the number of traps available to the fishery, it is likely that the quantity of bycatch and prerecruit crabs captured within the commercial stone crab fishery is substantial. Use of cull rings will reduce the unnecessary mortality associated with the stone crab fishery and benefit the ecosystem and stone crab stock in Florida.

During the 2016–2017 fishing season, the SCFIM distributed 1,000 55.6-mm ($2\frac{3}{16}$ in) cull rings among 10 commercial fishers in the Florida Keys Commercial Fishing Association. This effort was intended to gauge the interest of industry members in incorporating cull rings into their traps. Fishers who installed a cull ring in their traps did not provide catch data, but reported anecdotally that they liked the performance of the rings and thought they would improve the efficiency of their operations. At the beginning of the 2017–2018 stone crab season, one fisher arranged for the manufacture of several thousand 55.6-mm cull rings. These rings were sold for US$2.47 each to other fishers who used them in their traps. Fishers who used the rings expressed that they will continue to modify their existing traps with rings, but would prefer trap manufacturers mold rings into new traps.

Since the 2011 transfer of regulatory management of the stone crab fishery from the federal government to the state of Florida, there have been no attempts to curb overcapitalization or the possible negative ecological effects of traps. The most substantial change that occurred before the transfer of responsibility was the implementation of the passive trap reduction program in 2001. The benefits of this plan, however, will not be fully realized until 2048. Given the slow pace of trap reduction, the negative trend in landings, and increased effort, it is imperative that the fishery reduce its nontarget impact by using cull rings. Therefore, we recommend that a cull ring no smaller than 55.6 mm ($2\frac{3}{16}$ in) be used statewide in Florida.

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