Taylor & Francis
Taylor & Francis Group

North American Journal of Fisheries Management

ISSN: 0275-5947 (Print) 1548-8675 (Online) Journal homepage: http://www.tandfonline.com/loi/ujfm20

Evaluating the Potential for a Sex-Balanced Harvest Approach in the Recreational Summer Flounder Fishery

Jason M. Morson, Daphne Munroe, Ryan Harner & Rachel Marshall

To cite this article: Jason M. Morson, Daphne Munroe, Ryan Harner & Rachel Marshall (2017) Evaluating the Potential for a Sex-Balanced Harvest Approach in the Recreational Summer Flounder Fishery, North American Journal of Fisheries Management, 37:6, 1231-1242, DOI: 10.1080/02755947.2017.1362490

To link to this article: http://dx.doi.org/10.1080/02755947.2017.1362490

Accepted author version posted online: 21 Aug 2017.
Published online: 21 Aug 2017.

North American Journal of Fisheries Management 37:1231–1242, 2017

ISSN: 0275-5947 print / 1548-8675 online
DOI: https://doi.org/10.1080/02755947.2017.1362490

MANAGEMENT BRIEF

Evaluating the Potential for a Sex-Balanced Harvest Approach in the Recreational Summer Flounder Fishery

Jason M. Morson,* Daphne Munroe, Ryan Harner, and Rachel Marshall
Haskin Shellfish Research Laboratory, Department of Marine and Coastal Sciences, Rutgers, The State University of New Jersey, 6959 Miller Avenue, Port Norris, New Jersey 08349, USA

Abstract
Summer Flounder *Paralichthys dentatus* support important recreational and commercial fisheries along the northeast and mid-Atlantic coasts of the USA. In the recreational sector, management efforts to constrain harvest below the maximum allowable catch have typically involved increasing the minimum landing size; however, females grow faster than males. Thus, reliance on increased minimum size limits as a management strategy has resulted in approximately 90% of the recent recreational landings being large, female fish. We evaluated the potential for slot limits to produce a sex-balanced harvest in the recreational Summer Flounder fishery. To estimate the size- and sex-specific vulnerability, we sampled the landed and discarded fish (*n* = 3,290) caught by recreational anglers on select party boats from New Jersey to Rhode Island during the 2016 recreational fishing season. We then examined the performance of a wide array of slot limits to estimate which would have promoted a more sex-balanced harvest while maintaining a fixed fishing mortality given the observed catch composition. We demonstrate that slot limits applied to the recreational Summer Flounder fishery have the potential to simultaneously meet multiple management objectives, including the conservation of female biomass while maintaining a fixed fishing mortality; however, no single slot limit performed best at all sampling locations. Results should therefore be viewed as optimal given the observed catch composition for the year, fishing mode, and locations that were observed, and further evaluation of interannual, spatial, and fishing mode variability is warranted.

Targeted fishing of certain species within an ecosystem or a particular demographic within a population is known as selective fishing, an activity that may lead to detrimental imbalances (Law 2000; Bundy et al. 2005; Daan et al. 2005; Jorgensen et al. 2007; Anderson et al. 2008). Distributing a moderate fishing mortality across the widest possible range of species, stocks, and demographics in an ecosystem in proportion to their natural productivity could reduce the negative effects of selective fishing on biodiversity and population productivity (Zhou et al. 2010; Garcia et al. 2012). This "balanced harvest" approach has gained traction as ecosystem-based strategies to fisheries management become more popular, but the purported necessity and benefits of a blanket balanced harvest approach continue to be debated (Anderson et al. 2016; Jacobsen et al. 2013; Froese et al. 2015, 2016; Breen et al. 2016; Kolding et al. 2016). There is, however, strong evidence that at least sex-selective harvesting can have a negative impact on reproductive rates and stock productivity as well as alter sex ratio and life history (Clark and Tait 1982; Orensanz et al. 1998; Alonzo and Mangel 2004; Hamilton et al. 2007; Hutchings and Rowe 2008). When feasible, fishing regulations that promote exploitation of male and female fish in equal proportions are therefore often preferred over those that result in a female-biased harvest.

Summer Flounder *Paralichthys dentatus* support important recreational and commercial fisheries along the northeast and mid-Atlantic coasts of the USA. In 2015, an estimated 12.5 million Summer Flounder were caught in the recreational fishery alone (Terceiro 2016). In this sector, management efforts to constrain harvest below the maximum allowable catch have typically involved increasing the minimum landing size; however, Summer Flounder are sexually dimorphic. Females grow faster and mature at a larger size than males (Poole 1961; Morse 1981; Packer et al. 1999). Thus, reliance on increased minimum size limits as a management strategy has resulted in approximately 90% of the recent recreational landings being female fish (Morson et al. 2012, 2015). Furthermore, the female fish that are targeted are also the largest, and therefore potentially the most fecund fish in the population (Morse 1981;

*Corresponding author: jmorson@hsrl.rutgers.edu
Received March 17, 2017; accepted July 26, 2017

Berkeley et al. 2004; Birkeland and Dayton 2005; Hixon et al. 2013; Shelton et al. 2015; Stige et al. 2017).

Slots limits offer an alternative management approach to traditional minimum size limits in that they restrict landings to some intermediate range of sizes while large and small fish are released (Gwinn et al. 2013). In the Summer Flounder recreational fishery, it was previously demonstrated that slot limits have the potential to increase landings in numbers under a fixed fishing exploitation rate by weight (Bochenek et al. 2010; Powell et al. 2010). If smaller males are vulnerable to recreational fishing effort, a similar approach that redirects some fraction of the fishing mortality toward smaller-sized fish may also balance the fishing mortality with respect to sex. However, the only information available on the sex composition of the Summer Flounder recreational catch comes from fish that were landed and are therefore larger than the minimum size limit (Morson et al. 2012, 2015). Without an estimate of the sex composition for fish below the minimum landing size, it is not possible to evaluate the sex-specific outcomes of such alternative management options.

Here we evaluate the potential for slot limits to produce a sex-balanced harvest in the recreational Summer Flounder fishery. To estimate the size- and sex-specific vulnerability, we sampled all landed and discarded fish caught by recreational anglers on select party boats from New Jersey to Rhode Island during the 2016 recreational fishing season. We then examined the performance of a wide array of slot limits to estimate which would have promoted a more sex-balanced harvest while maintaining a fixed fishing mortality given the observed catch composition.

METHODS

Field program.—Data collection focused on three states: New Jersey, New York, and Rhode Island; and one fishing mode: for-hire mode. In 2016, these states accounted for 82% of the total catch by state; however, the for-hire fishing mode accounted for only 5% of the total catch by mode. While the for-hire mode accounted for only a small fraction of the total catch, the private mode, which accounted for 89%, operated across a similar spatial scale. In 2016, 34% and 31% of the total catch in the for-hire and private modes, respectively, came from open ocean waters less than or equal to 3 mi from the coast. In the same year, 42% and 54% of the total catch in the for-hire and private modes, respectively, came from inland waters (National Marine Fisheries Service [NMFS], Fisheries Statistics Division, personal communication). Given the two fishing modes access the same areas, data collection focused on the for-hire mode. The larger, for-hire vessels had space for up to 75 anglers, which significantly increased the sample size potential on any one sampling trip.

Data collection spanned one entire recreational fishing season from May 23, 2016, through September 16, 2016. Fish were collected bi-weekly aboard participating fishing vessels from Cape May (eight trips) and Atlantic Highlands (eight trips), New Jersey; Captree (nine trips) and Montauk (10 trips), New York; and Point Judith, Rhode Island (six trips; Figure 1). The total length of every Summer Flounder caught, whether landed or discarded, on each trip was measured. In addition, the sex for all landed Summer Flounder was recorded. Since Summer Flounder must be dissected to determine sex, 10 discarded fish were also sacrificed within predetermined fish length and water depth bins on each sampling trip (Table 1). A sex ratio—by depth bin, length bin, and trip—was applied to any unsexed discarded fish to assign sex to the entire discarded portion of the catch (Table 1).

Analysis.—To estimate the effect of different slot limits on three performance metrics—the total number of dead fish (landings + dead discards), the biomass of dead females, and the ratio of dead discards to total number dead—we simulated outcomes from 21 potential slot limits. The smallest lower size limit evaluated was 14 in (the minimum size limit in the commercial fishery), and the largest upper size limit evaluated was 21 in (the largest minimum size ever implemented in the recreational Summer Flounder fishery). The width of the slot limits varied from a minimum width of 2 in to a maximum width of 7 in.

A slot limit can be defined several ways, but here we are referring to a regulation where only fish within a minimum and maximum size limit could be kept, while all fish that are greater than the maximum size or less than the minimum size must be discarded. Since we did not record catch rate per angler and therefore could not evaluate alternative bag limits within a given slot limit, all fish between the minimum retention size and maximum retention size of a slot limit were assumed to be kept (no bag limit). Each slot limit was imposed on the observed catch and catch composition data overall as well as by location and depth category, assuming effort was fixed at what was observed. Finally, 10% mortality was applied to all discarded fish in conformity with the recreational discard mortality rate currently applied in the Summer Flounder stock assessment (Terceiro 2016).

To convert observed individual fish lengths (in) to estimated individual fish weights (lb), we applied sex-specific parameters from Morse (1981) for the equation

$$w(l) = \alpha l^{\beta}.$$

The total number dead N_d for each simulated slot limit s was calculated as

$$N_{ds} = N_{Ls} + (0.10 \times N_{Ds}),$$

where N_L is the total number of fish that were landed, and N_D is the total number of fish that were discarded. The biomass of dead females, F_d, was calculated as

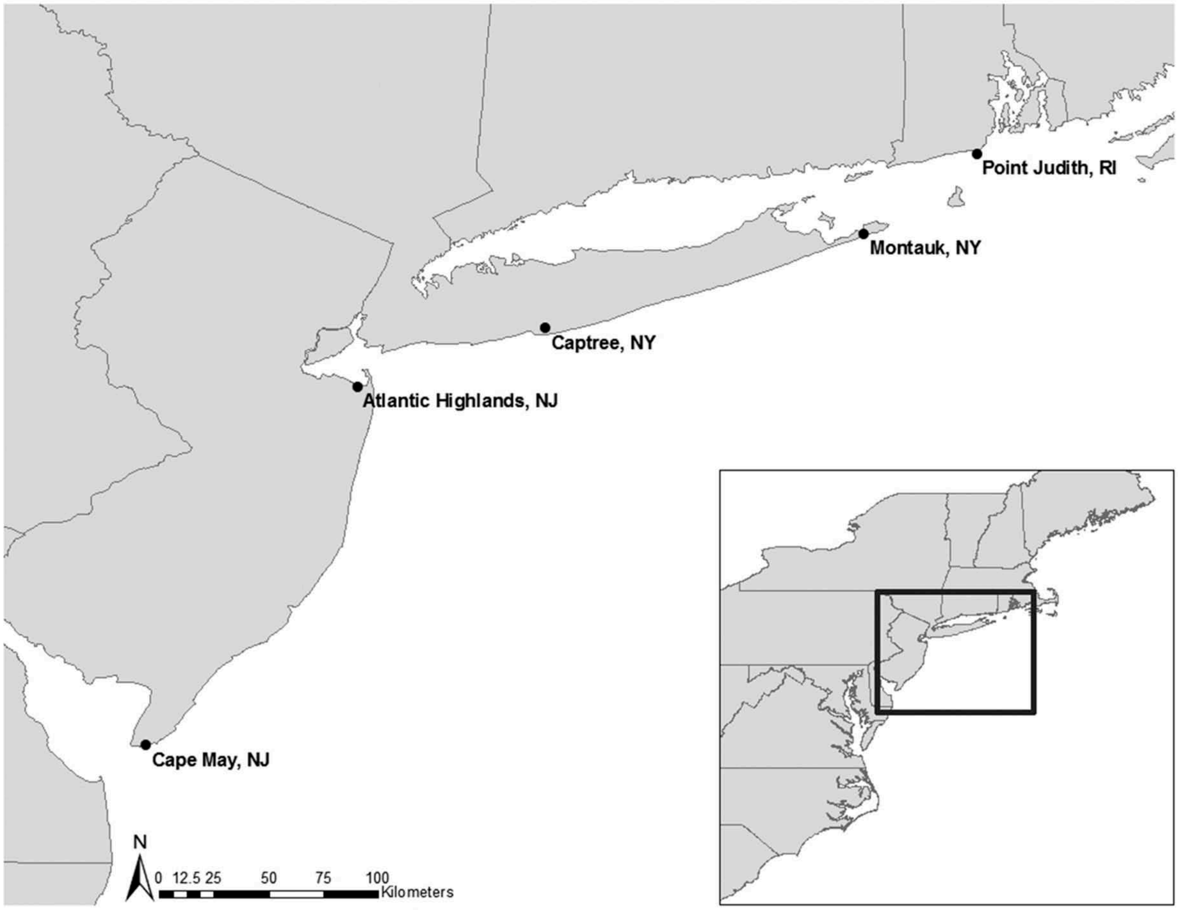

FIGURE 1. Map of sampling locations.

$$F_{ds} = \left[\sum_{i=1}^{n} w_{i_{L_{f_s}}} + \left(0.10 \times \sum_{i=1}^{n} w_{i_{D_{f_s}}} \right) \right],$$

where w is the weight in pounds of fish i, and f denotes female fish. Finally, the ratio of dead discards to total dead was calculated as

$$R_{ds} = \frac{(0.10 \times N_{Ds})}{N_{Ds}}.$$

The influence of each slot limit on these metrics was evaluated separately using the observed catch composition at each sampling location. For each slot limit, we calculated the proportional change from the observed metric at an 18-in minimum retention size to the calculated metric given the slot limit. Slot limits that produced a 10% or less change, whether negative or positive, in the total number of dead fish were deemed suitable alternatives in that they would not have resulted in a significant change in fishing mortality given total catch and total effort was fixed at what was observed. In other words, only slot limits that kept fishing exploitation rate near constant were viewed as potential alternatives to the 18-in minimum retention size.

TABLE 1. Length and depth categories for subsampling the sex of discarded fish.

Length bins (in)	Depth bins (ft)
8.0–9.9	0–25.4
10.0–11.9	25.5–50.4
12.0–13.9	50.5–75.4
14.0–15.9	75.5+
16.0–17.9	

RESULTS

Observed Catch Composition

Under an 18-in minimum size restriction, we observed a total catch of 3,290 Summer Flounder by recreational anglers on 41 directed party boat trips (Table 2; Figure 2). Of the total catch, 2,645 (80%) were discarded; however, the proportion of the catch that was discarded varied by region and by depth category (Table 2). The discard proportion was lower in deeper water and in more northern ports (Table 2) where smaller fish occurred less

TABLE 2. Total number of Summer Flounder sampled by port, depth range, outcome (landed–discarded), and sex. A dash indicates a given cell was not sampled, while a zero indicates that there were zero fish for that cell.

State	Port	Depth range (ft)	Outcome	Female	Male
New Jersey	Cape May	0–25	Landed	–	–
			Discarded	–	–
		25–50	Landed	–	–
			Discarded	–	–
		50–75	Landed	60	4
			Discarded	144	229
		75+	Landed	28	0
			Discarded	37	138
	Atlantic Highlands	0–25	Landed	0	0
			Discarded	9	24
		25–50	Landed	166	16
			Discarded	150	209
		50–75	Landed	8	2
			Discarded	75	118
		75+	Landed	–	–
			Discarded	–	–
New York	Captree	0–25	Landed	42	2
			Discarded	163	169
		25–50	Landed	13	0
			Discarded	53	74
		50–75	Landed	8	5
			Discarded	70	85
		75+	Landed	0	0
			Discarded	0	1
	Montauk	0–25	Landed	9	0
			Discarded	9	6
		25–50	Landed	120	12
			Discarded	214	390
		50–75	Landed	38	9
			Discarded	48	62
		75+	Landed	–	–
			Discarded	–	–
Rhode Island	Point Judith	0–25	Landed	4	8
			Discarded	0	2
		25–50	Landed	0	0
			Discarded	1	1
		50–75	Landed	31	13
			Discarded	26	50
		75+	Landed	31	16
			Discarded	12	70

frequently (Figures 3, 4). The proportion female increased with size, resulting in 87% (n = 558) of the landings and 38% (n = 1,011) of the discards being female overall (Figure 2). However, the sex ratio at length varied by location and by depth category. At a given length, the sex ratio was more heavily skewed toward female fish in shallower water and in more southern ports (Table 2; Figures 3, 4).

Simulated Catch Composition

Slot limits that kept the total number dead at or near that observed under the 18-in minimum size limit, herein referred to as "suitable," were all narrow, ranging from 2 to 4 in wide. Of the suitable slot limits, most contained 18 in within the slot limit and only once did the bottom of the slot limit fall below 16 in, when a 15- to 17-in slot limit was suitable in Atlantic Highlands, New

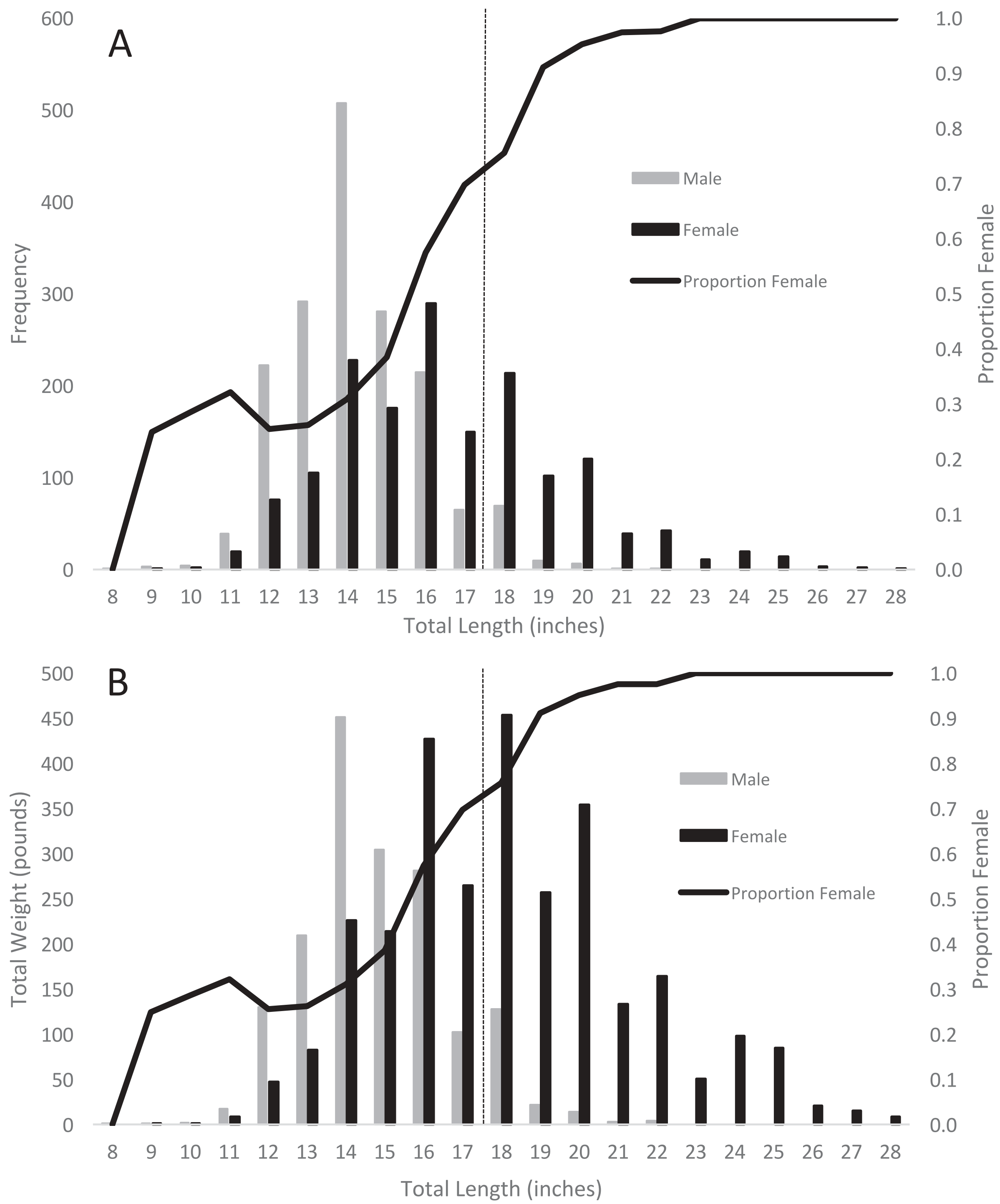

FIGURE 2. Total **(A)** number and **(B)** weight of male and female Summer Flounder collected at each 1-in length bin. Solid black line represents proportion female at length. Vertical dashed line represents the 18-in minimum landing size in 2016.

Jersey. All suitable slot limits reduced the total biomass of dead females, one of which, referred to herein as "optimal," produced the greatest reduction in total biomass of dead females. Few suitable slot limits had a significant impact on the proportion of the total dead made up of dead discards (Table 3).

No single optimal slot limit minimized dead female biomass at every location. Variation in length frequency and sex ratio at length observed across the different sampling locations produced varying suitable and optimal slot limits at each sampling location (Figure 3; Table 3). In Cape May,

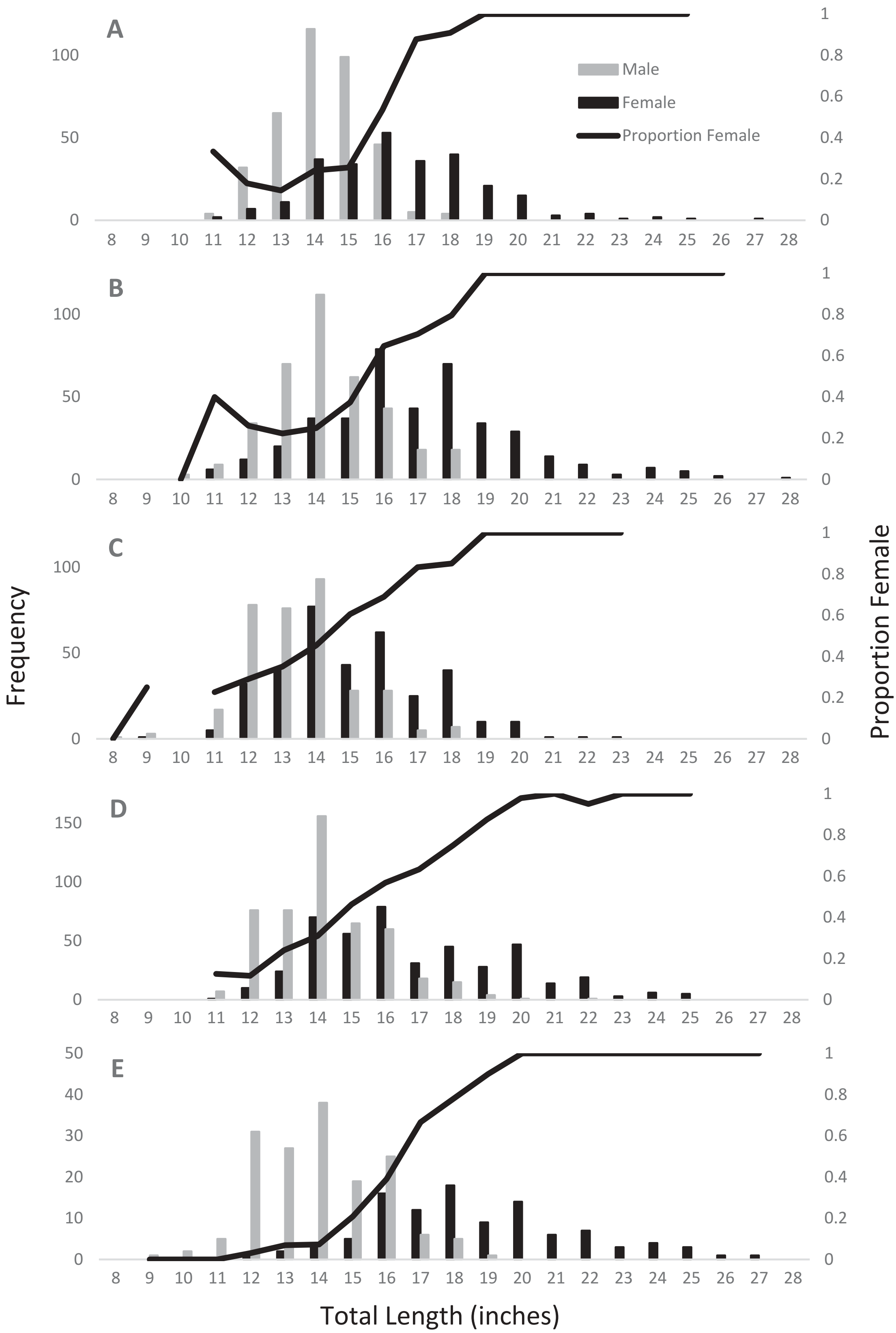

FIGURE 3. Total number of male and female Summer Flounder collected at **(A)** Cape May, New Jersey, **(B)** Atlantic Highlands, New Jersey, **(C)** Captree, New York, **(D)** Montauk, New York, and **(E)** Point Judith, Rhode Island, in each 1-in length bin. Solid black line represents proportion female at length. Note differences in primary *y*-axis for each panel.

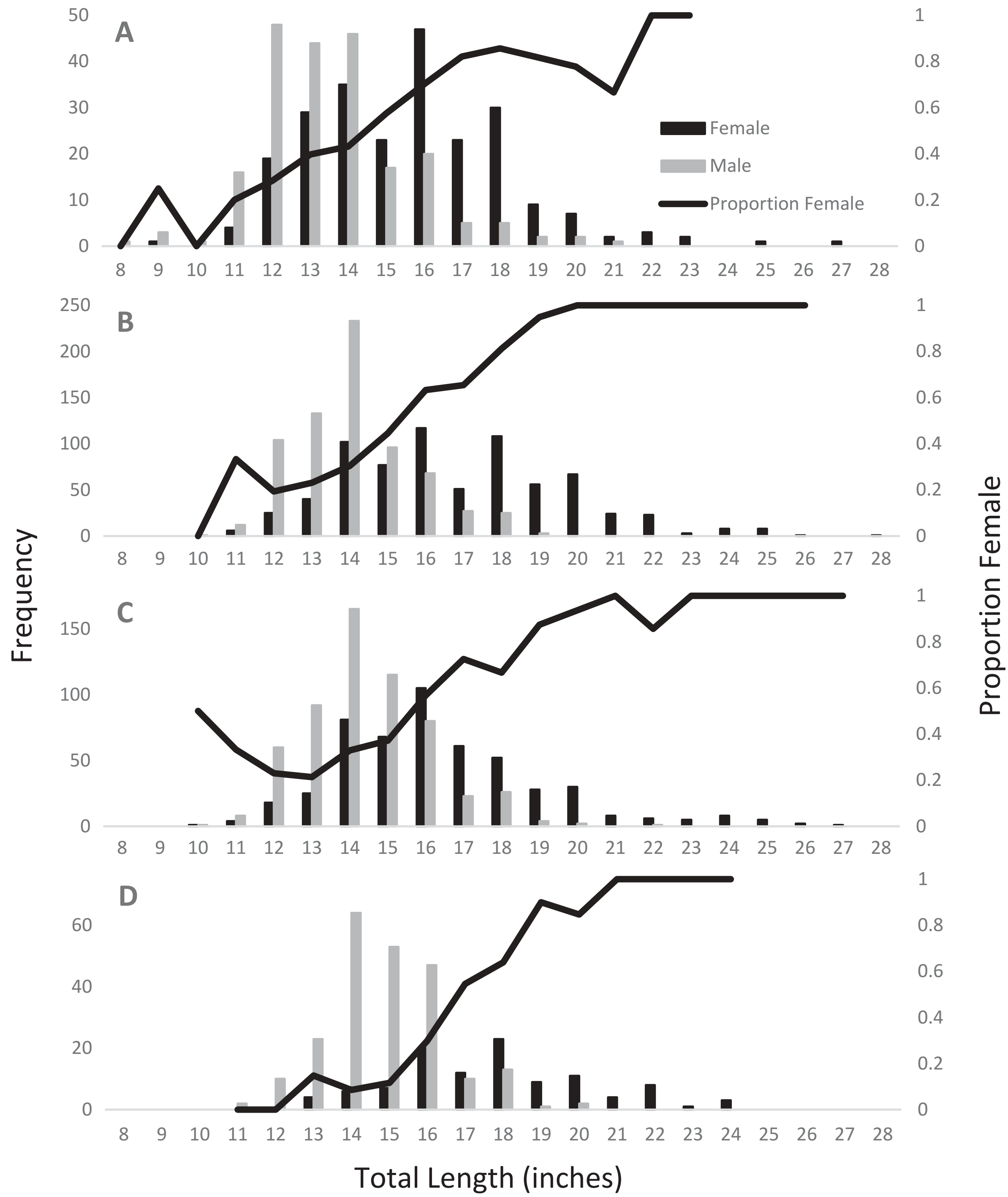

FIGURE 4. Total number of male and female Summer Flounder collected in **(A)** 0–25, **(B)** 25–50, **(C)** 50–75, and **(D)** 75+ ft of water at each 1-in length bin. Solid black line represents proportion female at length. Note differences in primary *y*-axis for each panel.

New Jersey, a 17- to 19-in slot would have been optimal, reducing dead female biomass by 31% (from 262.37 to 181.59 lb), while in the same state, in Atlantic Highlands, a 15- to 17-in slot would have been optimal, producing a 58% reduction in dead female biomass (from 537.85 to 226.89 lb). Similarly, in New York, the catch composition from Captree would have generated a 21% reduction in dead female biomass (from 181.1 to 143.93 lb) at an 18- to 20-in optimal slot limit, while in Montauk, the optimal slot limit was 16–18 in, which would have produced a 55% reduction (from 533.27 to 238.04 lb). Finally, in Point Judith, Rhode Island, among slot limits deemed suitable, a 3-in slot from

TABLE 3. Observed (18-in minimum size limit, top row) and simulated incremental slot limit performance metrics, including total number dead (N_d), dead female biomass (F_d), and ratio of dead discards to total dead (R_d). In parentheses are the percent changes in a given performance metric relative to the observed (18-in minimum size limit). Slot limits in bold italics are within +/–10% of the observed total number dead.

State	Port	Bottom of slot limit	Top of slot limit	Total number dead	Dead female biomass	Ratio of dead discards to total dead
New Jersey	Cape May	18.00		147	262.37	0.37
		14.00	15.99	321 (118%)	117.35 (−55%)	0.11 (−70%)
		14.00	16.99	411 (180%)	187.01 (−29%)	0.06 (−84%)
		14.00	17.99	447 (204%)	244.6 (−7%)	0.05 (−86%)
		14.00	18.99	487 (231%)	321.34 (22%)	0.03 (−92%)
		14.00	19.99	506 (244%)	369.87 (41%)	0.03 (−92%)
		14.00	20.99	519 (253%)	409.91 (56%)	0.03 (−92%)
		15.00	16.99	273 (86%)	153.98 (−41%)	0.15 (−59%)
		15.00	17.99	310 (111%)	211.57 (−19%)	0.12 (−68%)
		15.00	18.99	349 (137%)	288.31 (10%)	0.09 (−76%)
		15.00	19.99	368 (150%)	336.84 (28%)	0.08 (−78%)
		15.00	20.99	382 (160%)	376.88 (44%)	0.08 (−78%)
		16.00	17.99	190 (29%)	174.52 (−33%)	0.26 (−30%)
		16.00	18.99	230 (56%)	251.26 (−4%)	0.2 (−46%)
		16.00	19.99	249 (69%)	299.79 (14%)	0.18 (−51%)
		16.00	20.99	262 (78%)	339.83 (30%)	0.16 (−57%)
		17.00	***18.99***	***141 (−4%)***	***181.59 (−31%)***	***0.4 (8%)***
		17.00	***19.99***	***159 (8%)***	***230.13 (−12%)***	***0.34 (−8%)***
		17.00	20.99	173 (18%)	270.17 (3%)	0.3 (−19%)
		18.00	19.99	123 (−16%)	172.54 (−34%)	0.47 (27%)
		18.00	***20.99***	***136 (−7%)***	***212.58 (−19%)***	***0.41 (11%)***
		19.00	20.99	96 (−35%)	135.84 (−48%)	0.63 (70%)
	Atlantic Highlands	18.00		251	537.85	0.23
		14.00	15.99	301 (20%)	154.23 (−71%)	0.18 (−22%)
		14.00	16.99	411 (64%)	259.93 (−52%)	0.1 (−57%)
		14.00	17.99	466 (86%)	327.79 (−39%)	0.07 (−70%)
		14.00	18.99	545 (117%)	461.88 (−14%)	0.05 (−78%)
		14.00	19.99	575 (129%)	539.13 (0%)	0.04 (−83%)
		14.00	20.99	602 (140%)	616.99 (15%)	0.03 (−87%)
		15.00	***16.99***	***277 (10%)***	***226.89 (−58%)***	***0.2 (−13%)***
		15.00	17.99	332 (32%)	294.75 (−45%)	0.15 (−35%)
		15.00	18.99	411 (64%)	428.84 (−20%)	0.1 (−57%)
		15.00	19.99	441 (76%)	506.09 (−6%)	0.08 (−65%)
		15.00	20.99	467 (86%)	583.95 (9%)	0.07 (−70%)
		16.00	***17.99***	***242 (−4%)***	***254.37 (−53%)***	***0.25 (9%)***
		16.00	18.99	322 (28%)	388.46 (−28%)	0.16 (−30%)
		16.00	19.99	352 (40%)	465.71 (−13%)	0.13 (−43%)
		16.00	20.99	378 (51%)	543.57 (1%)	0.12 (−48%)
		17.00	18.99	212 (−16%)	282.76 (−47%)	0.3 (30%)
		17.00	***19.99***	***242 (−4%)***	***360 (−33%)***	***0.25 (9%)***
		17.00	***20.99***	***269 (7%)***	***437.86 (−19%)***	***0.21 (−9%)***
		18.00	19.99	188 (−25%)	292.14 (−46%)	0.35 (52%)
		18.00	20.99	214 (−15%)	370 (−31%)	0.29 (26%)
		19.00	20.99	134 (−47%)	235.91 (−56%)	0.53 (130%)
New York	Captree	18.00		132	181.1	0.47
		14.00	15.99	285 (116%)	162.17 (−10%)	0.16 (−66%)

TABLE 3. Continued.

State	Port	Bottom of slot limit	Top of slot limit	Total number dead	Dead female biomass	Ratio of dead discards to total dead
		14.00	16.99	366 (177%)	243.48 (34%)	0.1 (−79%)
		14.00	17.99	393 (198%)	283.12 (56%)	0.08 (−83%)
		14.00	18.99	436 (230%)	357.99 (98%)	0.06 (−87%)
		14.00	19.99	445 (237%)	380.35 (110%)	0.06 (−87%)
		14.00	20.99	454 (244%)	406.74 (125%)	0.06 (−87%)
		15.00	16.99	213 (61%)	175.18 (−3%)	0.25 (−47%)
		15.00	17.99	240 (82%)	214.82 (19%)	0.21 (−55%)
		15.00	18.99	283 (114%)	289.7 (60%)	0.16 (−66%)
		15.00	19.99	292 (121%)	312.05 (72%)	0.15 (−68%)
		15.00	20.99	301 (128%)	338.45 (87%)	0.14 (−70%)
		16.00	17.99	177 (34%)	167.65 (−7%)	0.32 (−32%)
		16.00	18.99	219 (66%)	242.53 (34%)	0.24 (−49%)
		16.00	19.99	228 (73%)	264.88 (46%)	0.22 (−53%)
		16.00	20.99	237 (80%)	291.28 (61%)	0.21 (−55%)
		17.00	***18.99***	***138 (5%)***	***161.22 (−11%)***	***0.44 (−6%)***
		17.00	19.99	147 (11%)	183.57 (1%)	0.41 (−13%)
		17.00	20.99	156 (18%)	209.97 (16%)	0.38 (−19%)
		18.00	***19.99***	***120 (−9%)***	***143.93 (−21%)***	***0.52 (11%)***
		18.00	***20.99***	***129 (−2%)***	***170.33 (−6%)***	***0.48 (2%)***
		19.00	20.99	87 (−34%)	95.45 (−47%)	0.77 (64%)
	Montauk	18.00		261	533.27	0.28
		14.00	15.99	404 (55%)	207.19 (−61%)	0.14 (−50%)
		14.00	16.99	529 (103%)	312.22 (−41%)	0.08 (−71%)
		14.00	17.99	573 (120%)	361.73 (−32%)	0.07 (−75%)
		14.00	18.99	627 (140%)	448.41 (−16%)	0.05 (−82%)
		14.00	19.99	656 (151%)	511.83 (−4%)	0.04 (−86%)
		14.00	20.99	699 (168%)	635.37 (19%)	0.03 (−89%)
		15.00	16.99	326 (25%)	249.51 (−53%)	0.2 (−29%)
		15.00	17.99	370 (42%)	299.03 (−44%)	0.16 (−43%)
		15.00	18.99	424 (62%)	385.71 (−28%)	0.13 (−54%)
		15.00	19.99	453 (74%)	449.13 (−16%)	0.11 (−61%)
		15.00	20.99	496 (90%)	572.66 (7%)	0.09 (−68%)
		16.00	***17.99***	***261 (0%)***	***238.04 (−55%)***	***0.28 (0%)***
		16.00	18.99	315 (21%)	324.71 (−39%)	0.21 (−25%)
		16.00	19.99	344 (32%)	388.13 (−27%)	0.19 (−32%)
		16.00	20.99	387 (48%)	511.67 (−4%)	0.15 (−46%)
		17.00	18.99	190 (−27%)	219.69 (−59%)	0.43 (54%)
		17.00	19.99	219 (−16%)	283.11 (−47%)	0.35 (25%)
		17.00	***20.99***	***262 (0%)***	***406.64 (−24%)***	***0.28 (0%)***
		18.00	19.99	175 (−33%)	233.59 (−56%)	0.47 (68%)
		18.00	20.99	218 (−16%)	357.13 (−33%)	0.36 (29%)
		19.00	20.99	164 (−37%)	270.45 (−49%)	0.51 (82%)
Rhode Island	Point Judith	18.00		119	222.94	0.14
		14.00	15.99	86 (−28%)	35.75 (−84%)	0.23 (64%)
		14.00	16.99	135 (13%)	57.61 (−74%)	0.11 (−21%)
		14.00	17.99	162 (36%)	76.54 (−66%)	0.07 (−50%)
		14.00	18.99	201 (69%)	110.67 (−50%)	0.04 (−71%)

TABLE 3. Continued.

State	Port	Bottom of slot limit	Top of slot limit	Total number dead	Dead female biomass	Ratio of dead discards to total dead
		14.00	19.99	215 (81%)	130.69 (−41%)	0.03 (−79%)
		14.00	20.99	232 (95%)	168.04 (−25%)	0.02 (−86%)
		15.00	16.99	104 (−13%)	54.87 (−75%)	0.17 (21%)
		15.00	17.99	132 (11%)	73.8 (−67%)	0.11 (−21%)
		15.00	18.99	171 (44%)	107.93 (−52%)	0.06 (−57%)
		15.00	19.99	184 (55%)	127.95 (−43%)	0.05 (−64%)
		15.00	20.99	201 (69%)	165.3 (−26%)	0.04 (−71%)
		16.00	17.99	103 (−13%)	68.2 (−69%)	0.17 (21%)
		16.00	18.99	142 (19%)	102.33 (−54%)	0.1 (−29%)
		16.00	19.99	155 (30%)	122.34 (−45%)	0.08 (−43%)
		16.00	20.99	172 (45%)	159.7 (−28%)	0.06 (−57%)
		17.00	18.99	93 (−22%)	80.46 (−64%)	0.21 (50%)
		17.00	***19.99***	***107 (−10%)***	***100.48 (−55%)***	***0.17 (21%)***
		17.00	***20.99***	***124 (4%)***	***137.83 (−38%)***	***0.13 (−7%)***
		18.00	19.99	79 (−34%)	81.55 (−63%)	0.26 (86%)
		18.00	20.99	96 (−19%)	118.9 (−47%)	0.2 (43%)
		19.00	20.99	57 (−52%)	84.78 (−62%)	0.4 (186%)

17 to 20 in would have been optimal, generating a 55% reduction in dead female biomass (from 222.94 to 100.48 lb). At some sampling locations, the potential to reduce dead female biomass came primarily from males being more accessible at lower sizes, for example, in Atlantic Highlands, New Jersey (Figure 3B), and in Montauk, New York (Figure 3D), while in other sampling locations it came primarily from the protection of larger females, for example, in Cape May, New Jersey (Figure 3A), and in Captree, New York (Figure 3C), and less from accessing smaller males at lower sizes.

DISCUSSION

The overall sex composition and the spatial and depth-dependent trends in sex ratio of large fish matched what has been previously reported for the recreational Summer Flounder fishery (Morson et al. 2012, 2015). Furthermore, the overall discard rate, 80%, is similar to the 79% discard rate estimated for the entire for-hire fishing mode in 2016 (NMFS, Fisheries Statistics Division, personal communication). The proportion female in the larger size-classes is higher than that observed in the commercial catch or on the NMFS–Northeast Fisheries Science Center trawl survey (Morson et al. 2015). However, while the observed sex ratio pattern for the larger fish suggests large males do not come inshore and are therefore not available to the recreational fishery when and where it takes place, we show here that smaller-sized males are both available inshore and show up in the recreational catch at smaller sizes. This is an important finding for two reasons. First, it suggests that any sex-specific movement or habitat use that produces such a highly skewed sex ratio in the landings must also be size specific. That is, while large male fish may remain offshore where they are less likely to be accessible to the recreational fishery, smaller males do move inshore in the spring–summer, where they are available to the recreational fishing effort. Sex- and size-dependent separation in space and time has been well documented in other sexually dimorphic flatfishes (Swain 1997; Swain and Morin 1997; Sahin and Gunes 2010; Loher and Hobden 2012), so the occurrence of this behavior in Summer Flounder is not surprising, and ecological theory for intraspecific partitioning of resources along a life history is well established (Schoener 1968). Second, the availability of male fish at lower sizes enables changes in size regulations to influence the sex composition of the catch. This second point is especially important given how much of the fishing mortality is being directed at the female portion of the stock in this fishery under the current minimum size restrictions and the desire to evaluate alternative management options that could promote a more sex-balanced harvest (Morson et al. 2012, 2015).

Slot limits have been demonstrated to produce higher harvest numbers, maintain natural age structure in the population, reduce discard mortality, positively influence recruitment potential, and conserve biomass across a variety of fish life histories (Birkeland and Dayton 2005; Powell et al. 2010; Koehn and Todd 2012; Law et al. 2012; Gwinn et al. 2013; Sanchez-Hernandez et al. 2016). Here we add additional support to a growing body of literature that suggests slot limits can simultaneously achieve a number of desired management goals and demonstrate that, for fish with sexually dimorphic growth, slot limits have the potential to distribute sex-biased fishing exploitation more evenly across both sexes. In the Summer Flounder recreational fishery, there is an obvious trade-off available to managers where the catch of large, heavy, female fish could be replaced by a similar number of smaller, lighter, male and female fish.

One important consideration in the evaluation of any slot limit relative to a minimum size limit is whether the lifetime spawner reproductive potential is negatively affected. Since nearly all of the lower ends of the slot limits prescribed here as optimal are only an inch or two smaller than the current 18-in size limit, both the current 18-in size limit and the prescribed optimal slot limits would allow fish the opportunity to spawn multiple times before recruiting to the fishery. Nevertheless, to fully evaluate the long-term impacts of varying slot limits on stock productivity, a spawning stock biomass-per-recruit analysis would be necessary (Haddon 2011). Therefore, a more appropriate method for evaluating viable slot limit options and potential outcomes is a management strategy evaluation that links annual management decisions on slot limits with a stock assessment model and includes annual, seasonal, and spatial dynamics in the population, the catch composition given the prescribed slot, and the fishing effort (Punt et al. 2014). Such an evaluation is beyond the scope of this work; however, the sex composition data now exist for the full range of sizes available to the recreational fishery, so the development of such a model is an obvious next step.

Several important limitations are inherent in the data and analysis we present herein. First, our approach assumes effort would have remained constant under alternative management scenarios. If, for example, a given slot limit would encourage more anglers to participate in the fishery than participated in it under an 18-in minimum size limit, the total catch under any alternative scenario may have increased, resulting in a higher total catch, and mortality, relative to the observed. Second, this work focused on the catch of the for-hire mode and did not sample the private or shore-based modes. It is possible the catch size and catch length and sex composition vary across these other fishing modes, which would alter the observed catch as well as the simulated outcomes of different slot limits. Finally, the observed catch is only representative of the catch in the year in which it was collected. Having observed a catch composition that appears to support a specific slot limit this year does not guarantee the same measure would be appropriate in any other year. For this reason, slot limits as a general strategy have the potential to be highly successful in achieving multiple management goals, particularly relative to a sex-balanced harvest in the recreational Summer Flounder fishery, but should be viewed as optimal given the observed catch composition for the year, locations, and mode we sampled, and further evaluation of interannual, spatial, and mode-specific dynamics is warranted.

In conclusion, the availability of male fish to the recreational fishing effort at smaller sizes, identified here for the first time, suggests that the conservation of large, female fish is achievable in this fishery with prescribed management actions. We demonstrate a few viable options that would have achieved either a more sex-balanced harvest or a reduction in dead female biomass under the catch conditions in the mode, location, and time we observed. However, we recommend that a more robust, spatially and temporally dynamic management strategy evaluation be used to estimate how alternative applications, including slot limits and trophy limits, would perform for this fishery in any given year so that multiple management goals, including limiting the mortality of large females, increasing angler satisfaction, and balancing harvest sex ratio under a fixed harvest rate, might be achieved simultaneously.

ACKNOWLEDGMENTS

We thank the captains and crews of the FVs *Porgy IV, Bonanza II, Big Mohawk, Fishermen, Laura Lee, Lazy Bones*, and *Gail Frances* for permitting us to collect samples aboard their fishing vessels. We are grateful to Sarah Borsetti, Emerson Hasbrouck, Scott Curato-Wagemann, Tara Froelich, and Kristin Gerbino for helping with data collection. Eleanor Bochenek assisted with coordinating sampling trips, for which we are thankful. Helpful comments were provided by Rich Wong and two anonymous reviewers. Partial funding for this work was provided by the National Science Foundation (NSF) Industry–University Cooperative Research Center Science Center for Marine Fisheries (SCeMFiS) through membership fees under the direction of the Industry Advisory Board; SCeMFiS administrative support is provided by NSF award 1266057. Additional funding was provided by the Save the Summer Flounder Fishery Fund and the Jersey Coast Anglers Association. The conclusions and opinions expressed herein are solely those of the authors.

REFERENCES

Alonzo, S. H., and M. Mangel. 2004. The effects of size-selective fisheries on the stock dynamics of and limitation in sex-changing fish. U.S. National Marine Fisheries Service Fishery Bulletin 102:1–13.

Anderson, C. N. K., C. Hsieh, S. A. Sandin, R. Hewitt, A. Hollowed, J. Beddington, R. M. May, and G. Sugihara. 2008. Why fishing magnifies fluctuations in fish abundance. Nature 452:835–839.

Anderson, K. H., J. L. Blanchard, E. A. Fulton, H. Gislason, N. S. Jacobsen, and T. Van Kooten. 2016. Assumptions behind size-based ecosystem models are realistic. ICES Journal of Marine Science 73:1651–1655.

Berkeley, S. A., C. Chapman, and S. M. Sogard. 2004. Maternal age as a determinant of larval growth and survival in a marine fish, *Sebastes melanops*. Ecology 85:1258–1264.

Birkeland, C., and P. K. Dayton. 2005. The importance in fishery management of leaving the big ones. Trends in Ecology and Evolution 20:356–358.

Bochenek, E. A., E. N. Powell, J. DePersenaire, and S. E. King. 2010. Evaluating catch, effort, and bag limits on directed trips in the recreational Summer Flounder party boat fishery. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science [online serial] 2:412–423.

Breen, M., N. Graham, M. Pol, P. He, D. Reid, and P. Suuronen. 2016. Selective fishing and balanced harvesting. Fisheries Research 184:2–8.

Bundy, A., P. Fanning, and K. C. T. Zwanenburg. 2005. Balancing exploitation and conservation of the eastern Scotian Shelf ecosystem: application of a 4D ecosystem exploitation index. ICES Journal of Marine Science 62:503–510.

Clark, C. W., and D. E. Tait. 1982. Sex-selective harvesting of wildlife populations. Ecological Modeling 14:251–260.

Daan, N., H. Gislason, J. G. Pope, and J. C. Rice. 2005. Changes in the North Sea fish community: evidence of indirect effects of fishing? ICES Journal of Marine Science 62:177–188.

Froese, R., C. Walters, D. Pauly, H. Winker, O. F. Weyl, N. Demirel, A. C. Tsikliras, and S. Holt. 2016. Reply to Anderson et al. (2016) “Assumptions behind size-based ecosystem models are realistic.” ICES Journal of Marine Science 73:1656–1658.

Froese, R., C. Walters, D. Pauly, H. Winker, O. L. F. Weyl, N. Demirel, A. C. Tsikliras, and S. Holt. 2015. A critique of the balanced harvesting approach to fishing. ICES Journal of Marine Science 73:1640–1650.

Garcia, S. E., J. Kolding, J. Rice, M. J. Rochet, S. Zhou, T. Arimoto, J. E. Beyer, L. Borges, A. Bundy, D. Dunn, E. A. Fulton, M. Hall, M. Heino, R. Law, M. Makino, A. Rijnsdorp, F. Simard, and A. Smith. 2012. Reconsidering the consequences of selective fisheries. Science 335:1045–1047.

Gwinn, D. C., M. S. Allen, F. D. Johnston, P. Brown, C. R. Todd, and R. Arlinghaus. 2013. Rethinking length-based fisheries regulations: the value of protecting old and large fish with harvest slots. Fish and Fisheries 16:259–281.

Haddon, M. 2011. Modeling and quantitative methods in fisheries. Taylor and Francis, New York.

Hamilton, S. L., J. E. Caselle, J. D. Standish, D. M. Schroeder, M. S. Love, J. A. Rosales-Casian, and O. Sosa-Nishizaki. 2007. Size-selective harvesting alters life histories of a temperate sex-changing fish. Ecological Applications 17:2268–2280.

Hixon, M. A., D. W. Johnson, and S. M. Sogard. 2013. BOFFFFs: on the importance of conserving old-growth age structure in fishery populations. ICES Journal of Marine Science 71:2171–2185.

Hutchings, J. A., and S. Rowe. 2008. Consequences of sexual selection for fisheries-induced evolution: an exploratory analysis. Evolutionary Applications 1:129–136.

Jacobsen, N. S., H. Gislason, and K. H. Anderson. 2013. Consequences of balanced harvesting of fish communities. Proceedings of the Royal Society B Biological Sciences 281:20132701.

Jorgensen, C., K. Enberg, E. S. Dunlop, R. Arlinghaus, D. S. Boukal, K. Brander, B. Ernande, A. Gardmark, F. Johnston, S. Matsumura, H. Pardoe, K. Raab, A. Silva, A. Vainikka, U. Dieckmann, M. Heino, and A. D. Rijnsdorp. 2007. Ecology: managing evolving fish stock. Science 318:1247–1248.

Koehn, J. D., and C. R. Todd. 2012. Balancing conservation and recreational fishery objectives for a threatened fish species, the Murray Cod, *Maccullochella peelii*. Fisheries Management and Ecology 19:410–425.

Kolding, J., S. M. Garcia, S. Zhour, and M. Heino. 2016. Balanced harvest: utopia, failure, or functional strategy? ICES Journal of Marine Science 73:1616–1622.

Law, R. 2000. Fishing, selection, and phenotypic evolution. ICES Journal of Marine Science 57:659–668.

Law, R., M. J. Plank, and J. Kolding. 2012. On balanced exploitation of marine ecosystems: results from dynamic size spectra. ICES Journal of Marine Science 69:602–614.

Loher, T., and J. Hobden. 2012. Length and sex effects on the spatial structure of catches of Pacific Halibut (*Hippoglossus stenolpis*) on longline gear. U. S. National Marine Fisheries Service Fishery Bulletin 110:46–51.

Morse, W. W. 1981. Reproduction of the Summer Flounder *Paralichthys dentatus* (L.). Journal of Fish Biology 19:189–203.

Morson, J. M., E. A. Bochenek, E. N. Powell, and J. E. Gius. 2012. Sex at length of Summer Flounder landed in the New Jersey recreational party boat fishery. North American Journal of Fisheries Management 32:1201–1210.

Morson, J. M., E. A. Bochenek, E. N. Powell, E. C. Hasbrouck, J. E. Gius, C. F. Cotton, K. Gerbino, and T. Froelich. 2015. Estimating the sex composition of the Summer Flounder catch using fishery-independent data. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science [online serial] 7:393–408.

Orensanz, J. M., J. Armstrong, D. Armstrong, and R. Hilborn. 1998. Crustacean resources are vulnerable to serial depletion – the multifaceted decline of crab and shrimp fisheries in the Greater Gulf of Alaska. Reviews in Fish Biology and Fisheries 8:117–176.

Packer, D. B., S. J. Griesbach, P. L. Berrien, C. A. Zetlin, D. L. Johnson, and W. W. Morse. 1999. Essential fish habitat source document: Summer Flounder, *Paralichthys dentatus*, life history and habitat characteristics. NOAA Technical Memorandum NMFS-NE-151.

Poole, J. C. 1961. Age and growth of the fluke in Great South Bay and their significance to the sport fishery. New York Fish and Game Journal 8:1–18.

Powell, E. N., E. A. Bochenek, and J. DePersenaire. 2010. Evaluation of bag-and-size-limit options in the management of Summer Flounder *Paralichthys dentatus*. Fisheries Research 105:215–227.

Punt, A., D. S. Butterworth, C. L. De Moor, J. A. A. De Oliveira, and M. Haddon. 2014. Management strategy evaluation: best practices. Fish and Fisheries 17:303–334.

Sahin, T., and E. Gunes. 2010. Seasonal variation in length, weight, and sex distribution of flounder (*Paralichthys flesus luscus*) in the southeastern Black Sea. Journal of Fisheries Sciences 4:238–245.

Sanchez-Hernandez, J., S. L. Shaw, F. Cobo, and M. S. Allen. 2016. Influence of a minimum-length limit regulation on wild Brown Trout: an example of recruitment and growth overfishing. North American Journal of Fisheries Management 36:1024–1035.

Schoener, T. W. 1968. Resource partitioning in ecological communities. Science 185:27–39.

Shelton, A. O., J. A. Hutchings, R. S. Waples, D. M. Keith, H. Resit Akcakaya, and N. K. Dulvy. 2015. Maternal age effects on Atlantic Cod recruitment and implications for future population trajectories. ICES Journal of Marine Science 72:1769–1778.

Stige, L. C., N. A. Yaragina, O. Langangen, B. Bogstad, N. C. Stenseth, and G. Ottersen. 2017. Effect of a fish stock’s demographic structure on offspring survival and sensitivity to climate. Proceedings of the National Academy of Sciences of the USA 114:1347–1352.

Swain, D. P. 1997. Sex-specific temperature distribution of American Plaice (*Hippoglossoides platessoides*) and its relation to age and abundance. Canadian Journal of Fisheries and Aquatic Sciences 54:1077–1087.

Swain, D. P., and R. Morin. 1997. Effects of age, sex and abundance on the bathymetric pattern of the American Plaice (*Hippoglossoides platessoides*) in the southern gulf of St. Lawrence. Canadian Journal of Fisheries and Aquatic Sciences 53:106–119.

Terceiro, M. 2016. Stock assessment of Summer Flounder for 2016. Northeast Fisheries Science Center, Reference Document 16-15, Woods Hole, Massachusetts.

Zhou, S., A. D. M. Smith, A. E. Punt, A. J. Richardson, M. Gibbs, E. A. Fulton, S. Pascoe, C. Bulman, P. Bayliss, and K. Sainsbury. 2010. Ecosystem-based fisheries management requires a change to the selective fishing philosophy. Proceedings of the National Academy of Sciences of the USA 107:9485–9489.