Current and Potential Yield per Recruit of Hogfish, *Lachnolaimus maximus*, in Florida

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ABSTRACT

Hogfish (*Lachnolaimus maximus*) is a valuable fishery species that lives on reefs of the Gulf of Mexico, Caribbean Sea, and Atlantic Ocean north to the Carolinas. In Florida, hogfish landings have been declining in recent years. Moreover, maximum size of hogfish landed in south Florida, where landings are greatest, is only half the maximum size of those landed in the eastern Gulf of Mexico. These trends in landings and fish size suggest continuing problems for the fishery. In this paper we explore some of the costs and benefits of increasing the minimum legal size at which hogfish can be captured in order to increase the yield per recruit of hogfish. We also comment on the potential additional benefit, in terms of increased recruitment, that could result from this management option.

KEY WORDS: Reef fish, age, growth, mortality, yield per recruit, hogfish

La doncella de pluma (*Lachnolaimus maximus*) es una especie pesquera valiosa que vive en los arrecifes del golfo de México, mar Caribe, y en el Océano Atlántico hasta las Carolinas. Los desembarques de doncella de pluma en la Florida han declinando en años recientes. Ademas, las tallas máximas en el sur de la Florida, en donde los desembarques son mayores, tienen solamente la mitad de la talla máxima del este del golfo de México. Estas tendencias en los desembarques y tamaños de los pescados sugieren que los problemas en esta pequería continuarán. En esta publicación exploramos algunos costos y beneficios del aumento a la talla legal mínima para incrementar el rendimiento-por-recluta de la doncella de pluma. También comentamos sobre el beneficio potencial adicional en términos de incremento en reclutamiento que podría resultar de esta opción en el manejo.

PALABRAS CLAVES: Doncella de pluma, rendimiento-por recluta

INTRODUCTION

Hogfish form harems in reef habitats of Florida, where they support a valuable commercial and recreational fishery. At Alligator Reef, in the Florida Keys, hogfish are common and conspicuous throughout the diel period at 25 - 30 m depths (Starck and Davis 1966, Stark 1968, Nybakken 1997). The diet of hogfish is dominated by invertebrates, and anglers use clams, squid, or small crabs as bait (McClane 1965,

Randall 1968). Hogfish are also targeted by divers with spears and often enter trap-fishing gear.

Hogfish are protogynous hermaphrodites (Davis 1976, Claro et al. 1989, McBride et al. 2001). Males have been observed to reach 9,915 g total body weight (824 mm fork length [FL] or 905 mm total length; McBride 2001). The Florida record weight for hogfish captured on hook and line is 8,863 g (19 lbs., 8 oz.). McBride (2001) modeled hogfish growth and found that the predicted maximum size of hogfish from the eastern Gulf of Mexico is twice that of hogfish from south Florida (939 versus 448 mm FL). The smaller maximum size of hogfish in south Florida compared to the eastern Gulf of Mexico may suggest higher levels of fishing mortality in south Florida. A minimum size limit of 305 mm FL (i.e., 12 inches FL) was implemented July 1, 1994, largely in response to observations of decreasing availability of large hogfish in the Keys (e.g., DeMaria 1996). The 12-inch size limit was based on data from Davis (1976), which showed that the smallest male that had completed sexual transformation was 295 mm (11.6 inches) FL. McBride (2001) reported, however, that the size at 50% sexual transformation was considerably larger: 389 mm (15.3 inches) FL. Because a single male controls a harem of as many as 15 females (Colin 1982), harvesting mature males could disrupt reproductive output for not only a specific male but also for the entire harem. Because sexual transformation appears to require a few months to complete and is most common during the non-spawning season, the harvest of mature males would at the very least require the females to disperse to other harems and could potentially disrupt the spawning activity of a harem for several months (McBride 2001). The exact effect that harvesting a male may have upon a harem's reproductive success depends on the social behaviors and stock-recruitment relationship of hogfish, neither of which have been described. However, sufficient data are available for assessing hogfish yield per recruit.

In this paper we first examine the status of the hogfish fishery, particularly in reference to the effect of the 1994 minimum-size regulation on hogfish landings in Florida. Age, growth, and mortality estimates were not available for hogfish when this minimum size limit was implemented. Here, we use recently available life-history information to examine hogfish yield per recruit and to predict the probable time lag between the passing of a new regulation and the time when the hogfish fishery can realize the full benefits of the regulation.

MATERIALS AND METHODS

Data about hogfish landed in the commercial fishery were taken from the Florida Fish and Wildlife Conservation Commission's Marine Fisheries Information System (MFIS). The MFIS contains data describing landings, effort, areas fished, ex-vessel value, and gear used during commercial fishing trips since 1986; we used edited data covering landings through August 2001 and unedited landings data through batch # 675. Hogfish sizes were characterized from the National Marine Fisheries Service's Trip Interview Program (NMFS, TIP) data. The TIP data

include lengths of hogfish landed by the commercial fisheries operating in various fishing locations and using various gears since 1991. Commercial landings data were grouped according to three fishing areas, depicted in Figure 1A: East (Atlantic Ocean and inshore waters north of Biscayne Bay), South (Biscayne Bay to Charlotte Harbor, including the Florida Keys), and West Florida (Gulf of Mexico and inshore waters north of Charlotte Harbor). All lengths were converted to fork lengths, if necessary, using the equations from McBride (2001):

$$FL = 8.48 + 1.184\,(SL) \qquad r^2 = 0.997 \quad (10 - 699 \text{ mm SL; } n = 1563),$$

$$FL = 12.35 + 0.8632\,(TL) \quad r^2 = 0.995 \quad (13 - 905 \text{ mm TL; } n = 1563),$$

where SL = standard length, FL = fork length, and TL = total length, measured in millimeters.

Recreational fishing data were taken from the NMFS Marine Recreational Fisheries Statistics Survey and included landings, effort, county of each interviewed angler's landings, gear used, and fish size. Regional estimates of recreational landings were calculated using post-stratification methods outlined in Gray et al. (1999). Recreational landings were estimated for six regions, depicted in Figure 1B: Northeast (Nassau – Flagler counties), Central East (Volusia to Martin counties), Southeast (Palm Beach-Dade counties), Southwest (Monroe-Pinellas counties), West (Pasco-Franklin counties), and Panhandle Florida (Gulf-Escambia counties).

We extracted von Bertalanffy growth parameters for use in this study from McBride (2001). The model is $FL = L_{inf}(1-e^{(-K[t-t_0])})$, where L_{inf} is the asymptotic length, K is the Brody growth coefficient (i.e., how fast fish size approaches L_{inf}), and t_0 is the predicted age at which fish length is zero. Although McBride (2001) estimated different sets of growth parameters for fish from the south Florida and eastern Gulf of Mexico samples, we use only the eastern Gulf of Mexico growth equation ($r^2 = 0.84$) in this study, $FL = 939(1-e^{(-0.074[t+2.01])})$. McBride (2001) concluded that the south Florida growth equation ($r^2 = 0.62$), $FL = 448(1-e^{(-0.231[t+1.02])})$ was based on a sample with an age structure that was truncated because of the high fishing mortality rate in that area. Therefore, we assume the eastern gulf parameter set represents the true growth potential of hogfish in both areas.

Yield-per-recruit analyses followed the method of Thompson and Bell (1934). Input data included average weight-at-age for ages 0 through 25 – predicted by using the growth model for eastern Gulf of Mexico hogfish (weight in grams = $9329(1-e^{-0.131(\text{age in years}+0.26)})^3$, $r^2 = 0.844$) – and a constant instantaneous natural mortality rate of 0.15/yr. The choice of natural mortality rate (M) was a compromise between the $M = 3/t_\lambda$ method (Gabriel et al. 1989) and the $M = 4.6/t_\lambda$ method (Royce 1972), where t_λ is the maximum observed age. The former implies a constant rate of natural mortality in which less than 5% of the cohort lives beyond t_λ, while the latter implies a constant rate of natural mortality in which less than 1% of the cohort lives beyond t_λ. When t_λ is 25 years, M = 0.12/yr and M=0.18/yr using the two methods. The instantaneous fishing mortality rates (F) used were extracted

from McBride (2001): 0.17/yr for south Florida and 0.06/yr for the eastern Gulf of Mexico. Yield per recruit was calculated using knife-edge recruitment at each age from 1 to 15 years. Current yield per recruit was estimated for each fishery by using as the age-at-recruitment the age at which hogfish reach the 50th percentile of the cumulative distribution of lengths of hogfish landed by each fishery. We defined optimum yield per recruit as the yield at the biological benchmark $F_{0.1}$, the fishing mortality rate at which the slope of a tangent to the yield response curve was one-tenth the slope of the yield curve at the origin (Gulland and Boerema 1973, Deriso 1987).

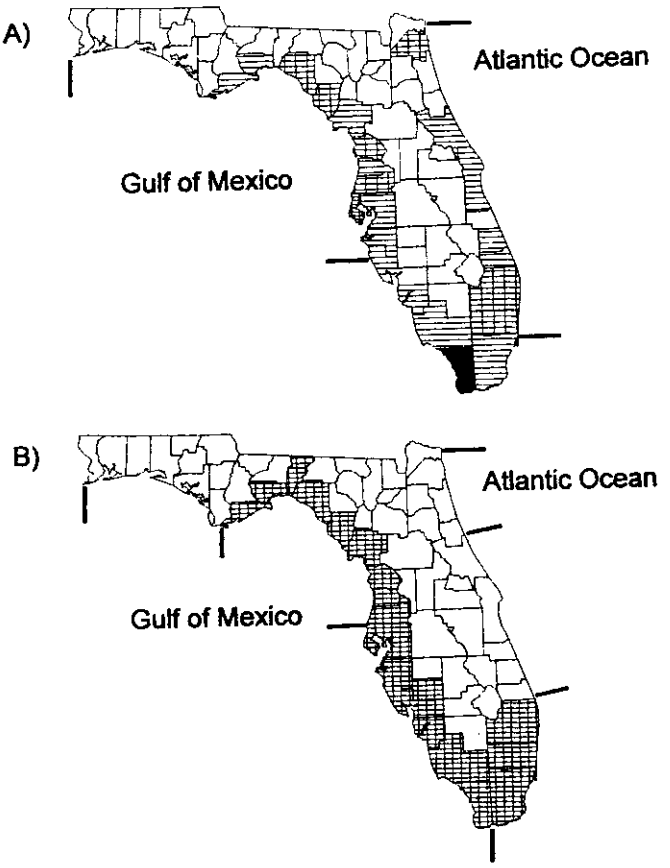

Figure 1. Geographic distribution of Florida's hogfish, *Lachnolaimus maximus*, landings in 2000. (A) Commercial landings are shown by county (marks delineate three regions): open (0-1,000 pounds), horizontal stripe (1,001-5,000 pounds), cross hatch (5,001-10,000 pounds), and solid (10,001-50,000 pounds). (B) Recreational landings are shown by region (marks delineate 6 regions): open (0-1,000 individuals), horizontal stripe (1,001-10,000 individuals; not evident here), and cross hatch (10,001-50,000 individuals).

RESULTS AND DISCUSSION

Description of the Commercial Fishery

Commercial fishing for hogfish was unregulated until 1994, when the State of Florida and the South Atlantic Fishery Management Council (SAFMC) enacted a 12-inch FL minimum size limit and restricted harvest to those who could demonstrate past participation in the reef fish fishery. These restrictions included a Restricted Species Endorsement issued by the Florida Fish and Wildlife Conservation Commission and a Reef Fish Permit issued by the National Marine Fisheries Service for the South Atlantic region. In 1999, the Gulf of Mexico Fishery Management Council (GMFMC) also adopted these regulations for fishermen operating in the Exclusive Economic Zone of the Gulf of Mexico.

Commercial landings of hogfish in Florida increased from 1987 to 1993 but declined from about 62,000 kg in 1993 to about 22,500 kg in 2000 (Table 1). The sudden change in trend for landings was coincident with the initial (i.e., 1994) implementation of hogfish fishing regulations and may have been due to the fact that a notable proportion of the catch, newly classified as undersized, was no longer being landed. The decline in landings also appears attributable to declining fishing effort in the past decade. Participation in the fishery, measured as the annual number of saltwater products license holders reporting hogfish landings, has dropped by more than 50%, from about 1,000 annually during 1987 - 1990 to fewer than 400 annually since 1998. Nearly all (99%) of these fishers reported landing less than 227 kg (500 pounds) of hogfish each year, so annual earnings from the sale of hogfish is small for most fishers.

The declining landings of hogfish since the mid-1990s has led to an overall decline in the value of the commercial fishery, even though the price per kg of hogfish has increased during this period (Table 1). The average ex-vessel price paid to fishers doubled from $2.25 per kg in 1987 to just over $4.50 per kg in 1996, and the price has remained at about $4.80 - 4.90 per kg since 1997. Nonetheless, because of the overall declines in landings, the total annual ex-vessel value of hogfish in Florida has fallen from $227,000 in 1993 to an average of $103,500 since 1998.

Most (67%) hogfish landed by commercial fishers during 1995 - 2000 were reported captured in waters adjacent to the southern tip of the Florida peninsula (Fig. 1A). Twenty-nine percent of landings were captured in the eastern Gulf of Mexico, along Florida's west coast, and only four percent were reported as caught in the Atlantic Ocean, along the east coast of Florida.

In Florida's commercial fishery, nearly all hogfish were landed by hook and line, by spear, or in traps. During 1995 - 2000, commercial fishers using these types of gear reported about 98% of the annual landings made each year in South Florida or in the eastern Gulf of Mexico. Of these types of gear, hook and line was used to capture more hogfish (19,769 pounds) on average during 1995 - 2000 than were traps (18,239 pounds) or spears (14,591 pounds). No single gear was responsible for >50% of the landings in any Florida region.

Table 1. Florida's annual hogfish, *Lachnolaimus maximus*, landings and value 1987-2000. Commercial landings are all reported ex-vessel sales. Recreational landings include the estimated weight and number of hogfish kept by anglers or reported released dead. See text for details and data sources.

A) Commercial landings

Year	Kg.	Lb.	$/Kg.	$/Lb.
1987	33,312	73,439	$2.25	$1.02
1988	34,412	75,865	$2.80	$1.27
1989	49,859	109,919	$2.87	$1.30
1990	52,713	116,211	$3.00	$1.36
1991	48,831	107,653	$3.20	$1.45
1992	53,270	117,438	$3.31	$1.50
1993	62,010	136,706	$3.66	$1.66
1994	42,393	93,460	$3.95	$1.79
1995	28,861	63,626	$4.50	$2.04
1996	27,396	60,397	$4.56	$2.07
1997	29,829	65,761	$4.83	$2.19
1998	21,297	46,950	$4.89	$2.22
1999	20,994	46,284	$4.81	$2.18
2000	22,490	49,582	$4.85	$2.20
Mean	37,691	83,092	$3.82	$1.73

B) Recreational landings

Year	Kg.	Lb.	Number
1987	244,591	539,222	253,676
1988	145,977	321,819	151,797
1989	78,968	174,092	104,856
1990	82,715	182,351	121,134
1991	193,557	426,713	179,094
1992	192,802	425,048	193,004
1993	150,606	332,024	218,539
1994	128,540	283,377	174,265
1995	153,153	337,638	128,701
1996	76,602	168,876	90,112
1997	106,066	233,832	92,176
1998	49,893	109,994	62,126
1999	81,579	179,847	91,033
2000	37,987	83,746	42,766
Mean	123,074	271,327	135,949

Description of the Recreational Fishery

Recreational fishing for hogfish was also unregulated until 1994, when the State of Florida and the SAFMC enacted a 12-inch FL minimum size limit and a 5-fish bag limit. As for the commercial regulations, the GMFMC did not adopt these regulations until 1999. Prior to the 1994 regulations, the number of hogfish landed annually varied between 105,000 and 254,000 but fell to a low of 43,000 in 2000 (Table 1). Landings, by weight, show a similar trend. These declines may partially be a result of the new size regulations and partially a result of declining angler effort (see below).

The recreational fishery for hogfish is centered in south Florida, but a significant portion of the landings is also made farther north in the eastern Gulf of Mexico (Figure 1B). During 1995-2000, 85% of the annual statewide landings were made in the Southeast and Southwest regions, especially in the Florida Keys, and 14% were landed in the West region, particularly in association with the Middle Ground reef area.

During 1995-2000, divers speared 71% of the hogfish and anglers hooked 29% of the hogfish, according to interviews with recreational fishers. The estimated number of recreational fishing trips on which fishers had caught or had tried to catch hogfish has declined dramatically since 1994, from a statewide average of about 98,000 trips during 1992 - 1994, to about 47,000 trips during 1997 - 1999, and to only 19,000 trips in 2000.

Hogfish Sizes

The smallest hogfish were generally caught in traps, larger hogfish were captured on hook and line, and the largest hogfish were caught with spears (Figure 2). The differences in the mean lengths of hogfish captured in these three gear types were more pronounced in the eastern Gulf of Mexico, varying by nearly four inches or 100 mm, than they were in south Florida. A two-way ANOVA showed that these differences – and specifically the interaction effect between harvest gear and area fished on fish size – were statistically significant ($P < 0.05$). The mean lengths of hogfish caught by using the three types of gear were very different in the eastern Gulf of Mexico (i.e., 11.2 inches [284 mm] FL for traps, 12.4 inches [315 mm] FL for hook and line, and 14.9 inches [378 mm] FL for spears). The sizes of hogfish landed with the three gear types in South Florida did not differ as much (i.e., 12.4 inches [315 mm] FL for traps, 13.1 inches [333 mm] FL for hook and line, and 13.9 inches [353 mm] FL for spears) as observed for the eastern Gulf of Mexico. Sizes of hogfish landed in Florida's Atlantic coast region were similar to sizes of those landed in south Florida, but too few measurements from the Atlantic regions were available for comparison.

The length at recruitment to each fishing gear type followed the same pattern as that of mean lengths: in the eastern Gulf of Mexico, 11.0 inches (279 mm) FL for traps, 11.5 inches (292 mm) FL for hook and line, and 14.0 inches (356 mm) FL for spears; in South Florida, 12.0 inches (305 mm) FL for traps, 13.5 inches (343 mm) FL for hook and line, and 14.0 inches (356 mm) FL for spears. These lengths

corresponded best to predicted lengths for age 3 (291 mm FL) and age 4 (337 mm FL) hogfish. For estimates of current yield per recruit (next subsection), both age 3 and age 4 were used as the age at knife-edge recruitment.

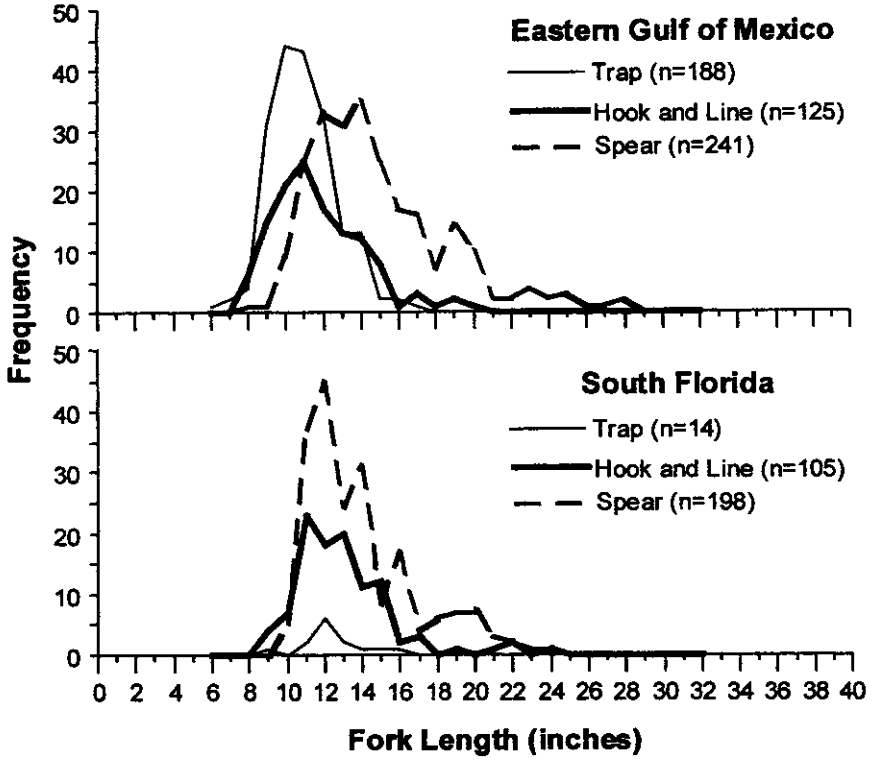

Figure 2. Size frequencies of hogfish, *Lachnolaimus maximus*, landed during 1995-2000 from the eastern Gulf of Mexico (Florida's west coast) and south Florida. Sizes are depicted separately by fishing gear type. Commercial and recreational landings are combined. (Number of fish = n).

We interpret these observed differences in sizes of landed hogfish to be largely the result of differences in the fishing regulations of each region, although larger hogfish may also exist in the eastern gulf because fishing mortality rates are lower there than in south Florida (McBride 2001). Most hogfish < 12 inches were from traps fished in the Gulf of Mexico, but it was not illegal to land these small hogfish from federal waters of the gulf until late 1999. Some of the hogfish < 12 inches caught on hook and line and spears in the Gulf of Mexico may also be from

federal waters. Hogfish landed in traps and hook and line in south Florida were larger, conforming more closely with the 1994 regulations of the State of Florida and SAFMC for those waters. All in all, it would appear that small (i.e., < 12 inches) hogfish were common in the landings during the latter half of the 1990s (Figure 3).

Since late 1999, the state and federal regulations governing the hogfish fishery have been the same; this consistency is expected to be of long-term benefit to the hogfish fishery. The trap fishery of the Gulf of Mexico is being phased out over the next several years, so the issue of release-related mortality is limited to anglers. No specific information on capture-release survival rates exists for hogfish, but studies on groupers (Serranidae) show that released fish have a high survival rate even when harvested from waters up to 44 m deep (Wilson and Burns 1996). Hogfish are known for remaining in the vicinity of diver activity, a behavior that makes this fish particularly vulnerable to spearfishing; however, spearfishers can see the fish before they shoot, so they should kill few undersized hogfish.

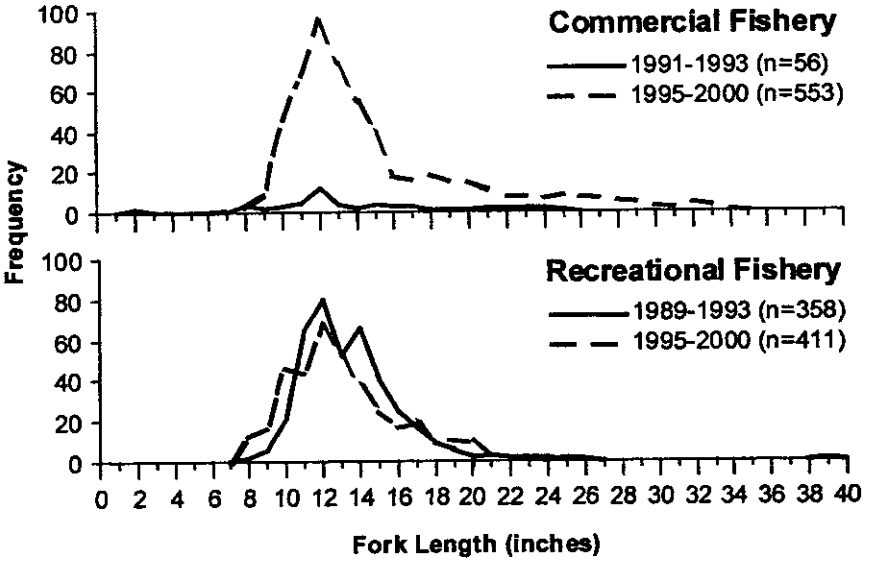

Figure 3. Size frequencies of Florida's hogfish, *Lachnolaimus maximus*, from commercial and recreational landings. Sizes are depicted before and after the 1994 regulations enacted by the State of Florida and the South Atlantic Fishery Management Council. Landings from all Florida regions and all fishing gear types are combined. (Number of fish = n).

Yield-per-recruit Analysis

Increasing the size limit can increase the fishery yield of hogfish in Florida, although the actual gains in yield are strongly dependent on the level of fishing. At optimum fishing mortalities ($F_{0.1}$), the greatest potential yield per recruit occurs when hogfish are recruited to the fishery at about 19 inches FL where $F_{0.1}$ is about 0.20/yr. If the current length at recruitment, modeled here as sizes corresponding to either age 3 or age 4, was changed to 19 inches FL then this would increase the optimal yield per recruit 20 - 33%, from 0.50 or 0.55 kg/recruit to 0.66 kg/recruit (Figure 4). However, current fishing mortality rates are 0.17 yr^{-1} in south Florida (McBride 2001), slightly less than the $F_{0.1}$ level at a 19-inch size-at-entry to the fishery. Therefore, a 19-inch FL minimum size limit in south Florida would increase the yield per recruit by only 9 - 20% above the current level. In the eastern Gulf of Mexico, where the current fishing mortality rate is even lower, 0.06/yr (McBride 2001), yield per recruit with a 19-inch FL minimum size limit would actually drop below the current level by 5 - 8%. If fishing mortality rates were maintained at present levels in both regions then the greatest yield per recruit could actually be achieved with 18-inch FL and 15-inch FL minimum size limits in south Florida and the eastern Gulf of Mexico, respectively (Figure 4). These would provide increases in yield per recruit of 11 - 23% in south Florida and 1 - 4% in the eastern Gulf of Mexico.

Increases in the minimum size limits may bring other benefits to the hogfish populations. For example, if such regulations delay the legal harvest of newly matured males, spawning success could improve as a result of increased harem stability. A 19-inch FL minimum size limit would increase the abundance of hogfish that are between 12 and 19 inches long. In south Florida, we would expect this change to result in more than a two-fold increase ($\exp^{5 yrs * F}$ where F = 0.17/yr) in the number of hogfish that reach a FL of 19 inches. The expected increase in the abundance of 19-inch hogfish in the eastern Gulf of Mexico is lower, 37%, than the expected increase in south Florida waters because current fishing mortality in the gulf is lower than it is in south Florida. This significant increase in the abundance of hogfish who reach 19 inches could, in theory, sustain or improve the reproductive output of a hogfish population if either the abundance or the size of males is related to the population's reproductive success. Sexual transformation appears to require a few months (McBride, 2001), and presumably, once a male is killed, the reproductive output of all the harem's females is zero, at least temporarily. Colin (1982) observed spawning behavior of hogfish but did not comment on how readily females move between harems or if male size affects the sex ratio or spawning frequency of a harem. Further behavioral observations should elucidate how long this problem persists and to what magnitude.

Increasing the minimum size at which hogfish may be captured may also help promote and maintain eco-tourism in the region. Larger hogfish are usually the sexually dimorphic males, which are often characterized as charismatic reef residents. Allowing hogfish to grow larger before they can be legally caught would result in more sightings of the males and of harem behavior and would eventually

provide more 'trophy' fish to be harvested by divers and anglers. Further discussion or research is needed to understand the social attitudes and cost-benefits of such regulatory options.

We have tried to outline some of the benefits that increasing the minimum size limit for hogfish might bring to the hogfish population and fishery. Changes in hogfish regulations would, however, adversely affect the fishers temporarily. Implementation of a new size regulation would be followed by a period of low legal catch rates before the average-sized hogfish could reach the new larger legal size. For example, hogfish in the Gulf of Mexico fishery measure about 12 inches at approximately age 3 and 19 inches at about age 8. Thus, it would take about 5 years for the size structure of hogfish to increase sufficiently in response to a 19-inch size minimum and for fishers to fully benefit from this specific regulatory option.

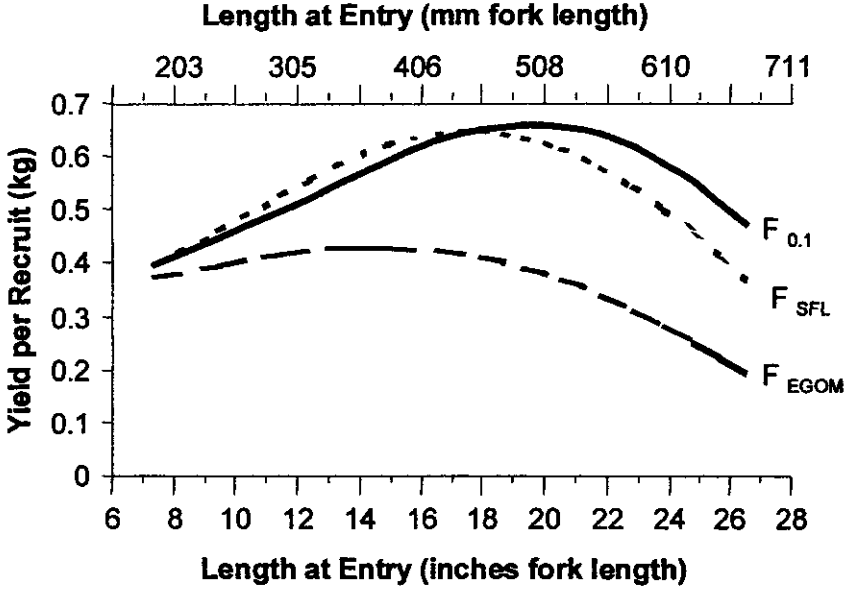

Figure 4. Estimated yield per recruit (kg) of hogfish, *Lachnolaimus maximus*, at various sizes-at-entry to the fishery (mm and inches) and fished at a benchmark mortality rates ($F_{0.1}$) and two observed mortality rates from McBride (2001): the current south Florida fishing mortality rate (F_{SFL}) and the current eastern Gulf of Mexico fishing mortality rate (F_{EGOM}).

CONCLUSIONS

Most hogfish landed in Florida before 2000 measured very close to the 12-inch (305 mm) FL size limit. Hogfish at this size are predicted to be age 3. But this species grows to 824 mm (32.4 inches) FL and reaches age 25. The observed maximum size is smaller in south Florida than in the eastern Gulf of Mexico, suggesting that growth overfishing is more severe in that region. This was confirmed by yield-per-recruit analyses. Increased yield should occur for hogfish caught in Florida, especially south Florida, if harvest was delayed until hogfish grew to larger sizes.

Maximum yield-per-recruit for hogfish would occur at a size larger than the current mean size at recruitment to the three main fisheries: trap, hook and line, and spear. Given an optimal fishing mortality ($F_{0.1}$), maximum yield per recruit is achieved at a mean size at recruitment of about 19 inches (483 mm) FL. There are other probable benefits associated with minimum size increases, including increased hogfish spawning success and the development of a trophy fishery. There would be short-term (about five years) costs to this size limit change because the number of legal-sized fish would be temporarily reduced.

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