Executive Summary

Goals
Stock assessment of black sea bass (BSB) has advanced considerably in recent years, however, critical uncertainties remain. Two key unknowns are: (1) the size, age, and sex (SAS) distribution of the population over the course of the spawning season and SAS selectivity of different fishing gears and (2) the effects of fishing on the sex ratio and population dynamics of this protogynous hermaphrodite. To address both of these unknowns, we conducted a geographically focused (reefs and wrecks off of central New Jersey) tagging experiment using conventional (T-bar) tags. The specific goals of this work were:

(1) Quantify size selectivity curves for male and female black sea bass caught by two different gear types: commercial traps and recreational hook-and-line, and

(2) Examine sex change among female black sea bass as a function of size, age, and season

Field sampling
In 31 sampling days, we tagged 1,498 BSB with internal anchor Floy tags and collected size, and age data, as well as scales for aging, from an additional 1,208 undersize black sea bass. We also collected 689 gonad samples from smaller fish (< 11 in) and recaptured fish, which were stored in ethanol after first fixing in formalin.

Laboratory analysis and ageing
We aged 1,998 black sea bass using scales, including most of the tagged black sea bass and 276 of the undersize black sea bass. Project collaborator Dr. David Berlinsky conducted histological analysis of the gonad samples to look for transitional individuals, i.e., those showing early signs of sex change such as the presence of both ovarian and testicular tissue in the gonad.

Recaptures of tagged fish
A total of 437 tagged fish were recaptured, including 29 fish originally caught by hook & line that we recaptured in commercial fish traps, 38 that we caught by trap and recaptured by hook & line. Of these recaptured individuals, sex at the time of recapture was determined for the 269 fish which were either captured by the study team or whose carcasses were returned by fishermen. Length was measured and sex determined in the 126 females that were tagged and recaptured. Of those, 108 remained female, 9 became male, and 9 were in transition when they were recaptured.

Outreach and collaboration with fishermen
We made a total of 31 tagging trips on fishing vessels, including 7 trips on a commercial pot vessel and 18 on charter or party boats plus an additional 6 tagging trips on Rutgers University vessels. 85 recreational fishermen have volunteered on tagging trips for a total of 210 volunteer days. 79 fishermen reported recaptures of tagged fish.

On January 19 and August 14, 2012 teacher training workshops were held to familiarize local elementary, middle, and high school teachers about the black sea bass project. Forty teachers
attended three sessions on black sea bass: 1) how to determine age using scales, 2) how to prepare otoliths for aging, and 3) black sea bass gut content analysis.

We have distributed posters advertising the tag return program to more than 15 bait and tackle shops, fish processing facilities, and public message boards (e.g., at the post office and supermarkets of coastal towns in NJ). There has been news articles about the project published in The Fisherman magazine, The Asbury Park Press, and Commercial Fisheries News. The project PIs have given 12 public talks about the project. Mikaela Provost, the graduate student whose MS thesis was based on this project, also gave a presentation on BSB gear selectivity to the Mid-Atlantic Chapter-American Fisheries Society (AFS) Meeting in November 2011. This talk won the best student presentation award. In August of 2012 Mikaela presented at the AFS national conference in Minneapolis-St. Paul, MN on gear selectivity and sex change in stock assessments.

We have had four undergraduate interns (from universities in NY, NJ, and MA) assisting with the research and conducting independent projects related to the overall project. Three of the students presented their preliminary results at an undergraduate research presentation at Rutgers in August, 2011. The fourth student graduated from Rutgers in May 2012, his honor thesis was on alternative reproductive strategies in black sea bass.

**Results**

Vulnerability of black sea bass to capture varied by size and sex and between commercial and recreational fishing gears. For commercial traps, males of intermediate size range (280–360 mm) were most likely to be recaptured. For recreational hook-and-line gear, vulnerability of males increased with size: the largest males (440–500 mm) had the highest change of being captured. Across most sizes (129–483 mm), commercial traps captured a significantly higher proportion of males at length compared to hook-and-line fishing gear. Size at 50% sex change was 365 mm and all sex changing females were 3–4 years old. Females that changed sex ranged from (initial size to recaptured size) 290 to 370 mm – 340 to 480 mm. Complete sex change events happened over the winter between the summer spawning seasons in 2011 and 2012. Based on the overall sex change rate and the distribution of fish sizes and ages in our sample, we estimate that slightly less than half (47%) of female black sea bass tagged in 2011 changed sex by the following spawning season in 2012.
Background

Black sea bass (BSB, Centropristis striata) are a member of the family Serranidae (sea basses and groupers) and are found in estuaries (juveniles) and structured bottom habitat from the Gulf of Maine to the Gulf of Mexico (Drohan et al. 2007). In the Mid-Atlantic Bight, BSB undergo a seasonal migration in the fall from their inshore spring and summer habitat to deeper continental shelf waters (Musick and Mercer 1977, Moser and Shepherd 2009). BSB is a protogynous hermaphrodite; individuals which begin life as females undergo sex reversal and become males later in life. The species supports important recreational and commercial fisheries throughout much of its range and is separated into two stocks in the Atlantic at Cape Hatteras, NC. The most recent assessment of the northern stock concluded that overfishing is not occurring, and the stock is not overfished. However, the review panel rejected the reference points from the new age-based model.

Both the assessment and an earlier review (Miller et al. 2009) identified several suggestions for BSB research, including: (1) improving estimates of the natural mortality rate (M) and potential changes in M with age; (2) examining stock structure and the possible existence of sub-stocks; (3) development of a stock-wide pot survey; (4) understanding the impact of fishing on the sex ratio and the implications for fecundity and spawning success. This research project focused on items 3 and 4 above and addressed one of the stated research priorities of the Mid-Atlantic research set-aside program: “Studies focused on life history and reproductive behaviors such as changes in sex ratio as a function of age and size or the evaluation of the sizes of territories in relation to mating or reproduction”

Current size regulations for BSB focus fishing mortality on larger individuals. For example, the minimum length for the New Jersey recreational fishery is 12 inches (30.5 cm) and the minimum length for BSB offered for sale in New Jersey is 11 inches (27.9 cm). At a length of 30 cm, approximately 30% of BSB are male and roughly 90% are sexually mature (males and females combined, Shepherd 2009).

Although little is known about the effects of fishing on BSB, studies of other protogynous hermaphrodites have shown changes in sex ratio and timing of sex-reversal. For example, Hamilton et al. (2007) found that in heavily fished populations of California sheephead, females showed a compensatory shift toward earlier maturation and sex-reversal. This resulted in a two-fold reduction in the average time spent as a mature female; however, the female:male sex ratio still increased. Similar changes in sex ratio have been found for other sex-changing species (Coleman et al. 2000).

The life-history of sequential hermaphrodites can have important implications for their population dynamics, assessment, and management. Simply ignoring sex change can lead to an overestimation of spawning biomass and errors in understanding the affects of fishing on the spawning potential ratio (Alonzo et al. 2008). One of the key uncertainties is how the sex-ratio
affects fertilization rates. Simulation studies (Brooks et al. 2008) suggest that to determine the optimal spawning stock index (males, females, or both), we need to know whether decreased fertilization occurs at higher female:male sex ratios.

Unfortunately, our understanding of sex reversal and the implications of changes in sex ratio on fertilization rates is extremely limited for BSB. Females are thought to undergo sex-reversal at an age of 2 – 5 years (Lavenda 1949, Mercer 1978). Both sexes mature at a younger age and smaller size in the southern portion of their range (McGovern et al. 2002). Potential environmental factors contributing to variability in the age of sex-reversal are poorly understood. A lab study, however, has shown that the presence of mature males inhibits sex-reversal by females (Benton and Berlinsky 2006). Six out of 24 female BSB held in groups of 8 females and no males underwent sex reversal during the 9 month study period. In contrast, none of the females held in groups with males underwent sex reversal.

McGovern et al. (2002) report a decline in the size at maturity for female BSB in the South Atlantic Bight between 1978-1982 and 1987-1998. There is also a report from an unpublished MS thesis (Alexander 1981) that the age and size at sex change has decreased and the female:male ratio has increased since the 1940s off of New York. In the Mid-Atlantic region, spawning of BSB is thought to peak in late spring (May – June, Drohan 2007). There is some indication that mature male BSB may defend harems of females (Nelson et al. 2003), a social structure seen in other protogynous hermaphrodites. Despite early recognition that: “It is necessary to understand the mechanisms controlling sex reversal in black sea bass before the effects of fishing pressure on the population can be evaluated” (Musick and Mercer 1977), we still know surprisingly little about sex reversal or changes in sex ratio for this species.

We also have limited knowledge of the size, age, and sex (SAS) selectivity of different fishing gears. The fishery consists of both active (trawl) and passive (hook-and-line and pots) fishing gears, used in different habitats and seasons. They are unlikely to share the same selectivity. There is some concern that the existing trawl survey does not adequately sample large mature males, as well as general doubt that a trawl survey is the most appropriate tool for sampling a structure-associated species like BSB (Shepherd 2009). Yield-per-recruit models, currently used to set biological reference points for BSB, are sensitive to selectivity and size-limits as well as discard mortality rates. A recent analysis of a large tagging study of BSB found no significant change in selectivity above a length of 29 cm, however, there is some evidence of a domed shape to the selectivity curve, and the analysis was not broken down by gear or sex (Shepherd and Moser 2009). Male and female BSB are thought to differ in their spawning behavior (Nelson et al. 2003), suggesting that they may also differ in their vulnerability to different fishing gears in ways that are not captured by size-selectivity alone. Sex-related differences in movement patterns and emigration rates represent a potential confounding factor for interpretation of tagging data. The length-based assessment model used for BSB estimates selectivity internally assuming an asymptotic selectivity pattern; however, independent estimates could help reduce uncertainty.
**Relevance to research priorities, assessment, and management**

This research represented an important first step toward properly accounting for the complex life history of BSB in the species’ assessment and management. Before we can begin to incorporate sex ratios into an assessment model, we need to: (1) understand how fishing affects the sex ratio during the spawning season and (2) develop survey methods that adequately sample the population and have known selectivity with respect to SAS.

The Mid-Atlantic research set-aside call for proposals lists the following as a priority for research on black sea bass: “Studies focused on life history and reproductive behaviors such as changes in sex ratio as a function of age and size or the evaluation of the sizes of territories in relation to mating or reproduction.” This proposal directly addresses this research priority.

It is important to note that the tagging study described here does not duplicate other recent tagging studies. The conventional tag study by Shepherd and Moser (2009) and Moser and Shepherd (2009) described movement patterns and estimated the fishing and natural mortality rates acting on BSB, resulting in changes to the natural mortality rate used in stock assessment. A large telemetry study of BSB using acoustic tags and an array of fixed receivers (Fabrizio et al. 2005), was used to assess habitat use and and dispersal rates. While both of these tagging studies add to our knowledge of BSB in important ways, neither study was designed to look at questions related to sex ratios and sex reversal.

**Note: The following text is taken directly from the relevant chapter of the MS thesis of Mikaela Provost, a graduate student at Rutgers University who conducted her MS research on this project. This represents the most complete and thorough summary of the research and the results**
Introduction
The process of fishing, whether by net, trap, or hook, is rarely effective at capturing individuals across all sizes and ages in wild fish populations (Lewin et al. 2006). As a consequence, fishing mortality rates vary by size and age, a phenomenon described as size selectivity (Beverton and Holt 1957, Quinn and Deriso 1999). Similarly, when the process of fishing does not effectively capture males and females in proportion to their natural abundances fishing mortality varies by sex and is a process known as sex selectivity.

The size selectivity of a fishery is influenced by many factors. Outside factors, such as management regulations (McClanahan and Mangi 2004), market value of fish species (Zimmermann et al. 2011), and cultural preferences (Aswani and Hamilton 2004) determine which fish species of what body sizes experience the highest mortality rate. The fish most ‘at risk’ of being captured is also a function of the interaction between fish and fishing gear, including factors such as gear placement in aquatic environments, gear design, and species’ feeding ecology (see Løkkeborg and Bjordal 1992 for examples). Variation in fish behavior (Williams et al. 2013), body size (Løkkeborg and Bjordal 1992), and movement throughout aquatic habitats and in the vicinity of fishing gear can influence the vulnerability of being captured (Parrish 1999). It is, therefore, imperative that life history be accounted for when assessing fishery selectivity.

Life history is especially important in sex selectivity for protogynous hermaphrodite fish species. A common life history characteristic of all protogynous hermaphrodites is that male fish tend to be larger and females are generally smaller in size (Charnov 1982). Since the sex ratio varies by size, it is expected that size-limited fishing gears will indirectly result in disproportionately high fishing mortality on male fish. There are other common protogynous life history characteristics that may directly increase the selectivity of males; these include, for example, sex-specific behavior (Black et al. 2011), sexual dimorphism (Munday et al. 2004), and sex-specific migratory patterns (Shapiro et al. 1993). Not only are males larger and, therefore, more vulnerable to size selectivity, male fish tend to be more aggressive (Warner and Swearer 1991) and have faster growth rates (Munday et al. 2004) which is expected to increase their susceptibility to fishing gear (Sutter et al. 2012). The potential sampling bias of fishing gear toward males, either through indirect or direct processes, causes protogynous species to be especially vulnerable to the consequences of sex selective fishing pressure.

Selectivity
In stock assessments, size selectivity curves are necessary for interpreting catch-at-age data. Size selectivity curves indicate the probability of capture at age or size, and describe which size classes are most vulnerable to being captured. Size selectivity curves can be sex and gear specific. Catch-at-age data cannot show which fish are most vulnerable to capture because catch data is an incomplete snapshot of the wild population’s size and age structure. Catch data alone
does not provide rates of capture by size across the size spectrum of body sizes. The process of calculating capture rates involves a comparison of size distributions between the wild population and catch, a process that is nearly impossible to do with populations in marine environments. Without knowing the complete size distribution in the wild, little can be inferred about a fish’s vulnerability from catch distributions alone. Size selectivity curves, in conjunction with catch-at-age data, are used to infer the sampling bias of fishing gear and make assumptions about the variation of fishing mortality across size for males and females.

Catch-at-age data can be interpreted in multiple ways. Catch data is usually dome-shaped over a range of sizes (Figure 1a), with relatively few small and very large fish in catch. There are many reasons to explain why small fish are not captured: small fish are avoided in fisheries with minimum size regulations, undersized individuals escape capture due to gear design (e.g. escape vents in traps, see Harada et al. 2007), or small fish do not occur in areas where intensive fishing practices occur. Even though small fish are rare in the catch, small fish remain relatively more abundant in the wild population than older and larger fish since older year classes have been reduced to smaller abundances because of annual natural mortality rates. Relatively low abundance of large fish in the catch; however, could indicate one of two possible scenarios. First, large fish may no longer be abundant in the population, and that few large fish in the catch is an accurate reflection of their relatively low abundance in the population. Or, large fish experience low capture rates because they avoid capture by fishing gear. In either case, the capture rate, or selectivity, of large individuals in the population varies.

The shape of size selectivity curves helps determine which of the two aforementioned scenarios explains why large fish are rare in the catch. Asymptotic size selectivity curves (Figure 1b) assume that selectivity increases with size and that fishing is mostly biased toward the largest sizes classes. Therefore, the relative abundance of large fish in the catch is greater than the relative abundance of large fish in wild populations. Dome-shaped size selectivity curves (Figure 3.1c), alternatively, assume that the largest size classes are not fully selected by fishing gear. Capture rates are highest for intermediate size classes since both small and large fish avoid capture and, consequently, experience the lowest fishing mortality.

Each selectivity curve, asymptotic or dome-shaped, can lead to very different management advice for fisheries because of their different assumptions about large fish. The perception that either absence or presence of large size classes in wild populations is important for assessing factors related to population growth (i.e. fertilization rates, recruitment, and mortality). In one case, the population is assumed to have relatively high abundance of large fish (dome-shaped, Figure 1c) whereas asymptotic selectivity assumes a relatively low proportion of large fish (Figure 1b). Such assumptions may have consequences for fishery managers and setting catch limits, minimum size regulations, and allowable fishing gear.
Knowing the size selectivity of different fishing gears is important for interpreting catch data and making assumptions about size structure in wild populations. For protogynous hermaphrodite fishes, estimating sex selectivity is particularly important because it can cause different mortality rates for males and females. Persistent sex selectivity may lead to unanticipated changes in the sex ratio and rate of sex change which can have lasting consequences on hermaphrodite fish population dynamics.

**Sex change**

The process of sex change plays an important role in hermaphroditic population dynamics. Population dynamics, defined as the study of how and why there are short- and long-term changes in size and age composition of a population (Quinn and Deriso 1999), present unique challenges to managers of hermaphroditic fish species. The process of changing sex inherently alters the number of males and females at size and age. Changes in the rate of sex change may affect size and age distributions of males and females which, in turn, can affect fertilization rates (Levitan 1992), egg production (Alonzo and Mangel 2004), and potentially recruitment (Brooks et al. 2008). It is expected that fishing pressure will alter the rate of sex change (see Hamilton et al. 2007 and Hawkins and Roberts 2004 for examples); however, the effect of fishing on sex change rates varies among hermaphroditic species (see Coleman et al. 1996 for examples). In hermaphroditic fish species the process of sex change is diverse (Munday et al. 2006) and may explain why the effect of fishing on sex change rates varies among protogynous species. Sex change has many forms, it can be protogynous (e.g. Benton and Berlinksy 2006) or protandrous (e.g. Moyer and Nakazono 1978); sex reversal may be triggered by shifts in local sex ratios (see Munday et al. 2006 for examples), population density (Lutnesky 1994), and size ratio (Buston 2003). For some species, sex change is a process that occurs throughout the entire year (e.g. red hind, Shapiro et al. 1993) or is restricted to one season (McGovern et al. 1998). The effects of fishing on rates of sex change have been far from uniform in hermaphroditic species. For example, female tusk fish (*Choerodon venustus*) underwent sex change earlier when fishing pressure increased (Platten et al. 2002), but had no effect on rates of male sex change in a protandrous shrimp (*Pandalus borealis*, Bergström 1997). Knowing when sex change occurs as a function of size, age, and season will help disentangle the relationship between fishing pressure and sex change rates.

**Life history of black sea bass and stock status**

Black sea bass (*Centropristas striata*) is an economically and culturally important protogynous hermaphrodite in the Middle Atlantic Bight. Their life history differs from black sea bass in the South Atlantic because they make an annual migration between the reefs located 5-10 miles off shore to the continental shelf (Musick and Mercer 1977). Every spring black sea bass return to reefs and artificial wrecks for the spawning season (May – October). In the Fall black sea bass will return to the continental shelf for the winter until the following Spring. Black sea bass hatch on reefs and wrecks and, as larvae, will spend their first winter on the inner continental shelf of
New Jersey (Kendall 1972, Able et al. 1995) as well as in estuaries (Able et al. 1995). There is not enough information yet in support of sex-specific migratory patterns in black sea bass.

Sex change in black sea bass has been studied through laboratory experiments and field observations. In the South Atlantic Bight, gonad histology shows males are present in every age and size class. Black sea bass in transition were most frequent 160-259 mm, and immediately following spawning events (March-May and September-October) 14% of black sea bass were transitioning (Wenner et al. 1986). A similar bimodal breeding pattern exists in the Gulf of Mexico (Cochran and Grier 1991). Black sea bass in the Middle Atlantic Bight, however, have one spawning event that occurs in May through October (Shepherd and Nieland 2010) and less is known about the percentage of transitioning individuals. Removal experiments in laboratory tanks show that sex change in black sea bass is controlled by social or visual cues; females will undergo sex change in the absence of large, dominant males (Benton and Berlinsky 2006).

Along the East Coast of the United States, black sea bass are divided into two separate stocks: there is a northern stock, Mid-Atlantic stock, located from the Gulf of Maine to Cape Hatteras, North Carolina and the southern stock, South Atlantic stock, from Cape Hatteras to southern end of Florida. The Mid-Atlantic and South Atlantic stocks are considered two separate populations of the same species. There is a third black sea bass management unit, Gulf of Mexico stock; fish from this stock represent a separate subspecies, Centropristis striata melana. The Mid-Atlantic stock is currently in good health: overfishing is not occurring and the population is not overfished, but questions still remain about the effect fishing has on sex change. For approximately three decades from 1975 to 2003 black sea bass were overfished (Shepherd and Nieland 2010). As part of the Northeast Data Poor Stocks Working Group in 2008, black sea bass were identified as a ‘data poor species’ because of their hermaphroditic life history, and inadequate fishery-independent survey methods. The working group concluded that additional field evaluation of black sea bass spawning behavior is needed to understand the implication of exploitation on black sea bass.

Objectives
This study addresses fundamental questions about sex selectivity and investigates the process of sex change in black sea bass along the coast of New Jersey. We focus on two objectives:

(1) Quantify size selectivity curves for male and female black sea bass caught by two different gear types: commercial traps and recreational hook-and-line, and

(2) Examine sex change among female black sea bass as a function of size, age, and season

To measure sex selectivity, the size distribution of a tagged group of males and females were compared with the size distribution of recaptured males and females with respect to each fishing gear. Selectivity curves will be modeled across size and age for each sex. This method has been
used in previous studies to measure selectivity and is the most direct method for estimating selectivity in wild populations (Hamley and Regier 1973, Miller and Fryer 1999). This study differs from previous studies of sex change in hermaphrodite species because we track the sex of individual fish to verify the occurrence or absence of sex change. In previous sex change studies, fish were sampled one or more instances throughout the year in order to examine gonads and identify the percentage of transitional individuals (Wenner et al. 1986, Shapiro et al. 1993, Coleman et al. 1996). This method is useful to measure the prevalence of sex change at the time of sampling, but is less useful if estimating the overall proportion of fish that change sex over a period of time. It is likely that sex change varies temporally throughout the year (see Coleman et al. 1996 and Shapiro et al. 1993 for examples) and that the duration of an individual undergoing sex reversal can occur within days or weeks (see Warner and Swearer 1991, Benton and Berlinsky 2006). The prevalence of sex change may be severely under-estimated if individual sex is not tracked over time through a tagging study.

This study also differs from previous sex change studies because here we track actual sex change events. In previously published literature it is conventional to assume that individuals identified as in ‘sexual transition’ based on gonad histology (Wenner et al. 1986) or by intermediate morphology (Hamilton et al. 2007) will complete the process without reverting back to their first sex (i.e. females transitioning to males would never stop their transition process and return to female in protogynous species). Removal studies conducted in laboratory tanks (Benton and Berlinsky 2006) and wild populations (Warner and Swearer 1991) suggest that the process of sex change, once started, is not interrupted; however, the triggers of sex change in the wild may be less clear-cut compared to removal experiments. By tagging individual fish and tracking their sex through time we can determine when actual sex change events occur.

The aim of this study is to measure sex selectivity in black sea bass and compare selectivity curves for commercial and recreational fishing gears. This study also estimated sex change rates as a function of size and age, and track when females are most likely to change sex throughout the summer and fall over a two year period.

Methods

Sampling location
Black sea bass were sampled from May to October in 2011 and 2012 on the coast of south-central New Jersey. Sampling was primarily based out of the Rutgers Marine Field Station in Tuckerton, New Jersey on Rutgers owned vessels. Black sea bass were also captured from two charter boats, R/V Karen Ann II (10.7 meters, Capt. Adam Nowalsky) and R/V Evelyn Ann (10.7 meters, Capt. Joel Mick), one party boat, R/V Miss Beach Haven (24.4 meters, Capt. Frank Camarda and Brant Whittaker), and one commercial fishing vessel, F/V Rachel Marie (13.1
meters, Capt. Eric Burcaw). Fishing sites ranged from 6 to 20 kilometers from shore in waters 15 to 30 meters depth.

Sampling sites were primarily chosen based on fish availability. Black sea bass are structure-oriented during the summer spawning season and are a popular sport-fish on artificial wrecks and reefs just offshore from the New Jersey coastline. Tug boats, subway cars, reef balls, tires, etc. have been purchased by local fishing clubs to provide excellent habitat for black sea bass. Based on advice from charter and commercial boat captains, we were able to identify highly productive reefs and wrecks for sampling black sea bass in 2011 and 2012.

Field sampling
Two methods were used to capture black sea bass: hook-and-line and commercial traps. Baited circle hooks were used between 8 AM and 5 PM on hook-and-line sampling days. Commercial traps were standard size, 106.7 cm long, 53.3 cm wide, and 34.3 cm tall. Each trap was outfitted with a standard size escape vent, cement anchor runners, and wire webbing on the outside of the trap. Both hook-and-line and trapping efforts to capture black sea bass were carried out in overlapping locations so that both types of fishing gear sampled from the same black sea bass population. After a soaking period of 5-14 days, traps were retrieved, black sea bass were measured, sexed, tagged, and traps were reset.

Males were identified by expressing milt with abdominal massage (DeGraaf et al. 2004). Females were identified by ovarian biopsy using a polypropylene cannula tube (1.49 mm outer diameter, 1.19 mm internal diameter) following the methods of Shehadeh et al. (1973) and Benton and Berlinsky (2006). In cases when sex could not be determined in situ, unidentified black sea bass were dissected in the laboratory to confirm sex. In order to determine age, five to ten scales were removed behind the pectoral fin and were pressed into acetate slides. Concentric annuli were counted on an Eyecom 3000 Com Fiche Reader. All black sea bass ages were validated by Josh Dayton, black sea bass expert ager, at the NOAA Aging Laboratory in Woods Hole, MA.

Tagging protocol
A mark-recapture study was done to estimate sex selectivity between recreational (hook-and-line) and commercial (traps) gears. The size and sex distribution of marked individuals was compared to the size and sex distribution of recaptured individuals caught in traps and by hook-and-line. Relative recapture rates of male and female tagged black sea bass for hook-and-line and commercial traps showed the sampling bias of each fishing gear.

In 2011 and 2012, 1,500 black sea bass >280 mm were tagged with Floy internal anchor tags (FM-84). This tag type was chosen because it has had long term retention rates in previous black sea bass studies (Moser and Shepherd 2009) and in other marine species (Waldman et al. 1991).
Catch and release procedures involved with capturing, tagging, and releasing black sea bass has contributed very little to fishing mortality (Bugley and Shepherd 1991).

All Floy tags had a unique identification number, telephone contact number, and “Rutgers Reward” printed on both sides in opposite directions such that the identification number was visible from the base and the top of the tag. Tags were color-coded by reward value in orange (n=1,299), earning a baseball cap if recaptured, and red (n=200) which generated a $100 reward if recaptured. To encourage the return black sea bass carcasses with tag returns from local fishermen, fishermen were entered into an annual $1,000 lottery for every tagged black sea bass carcass that was returned with the tag.

The tagging procedure followed the methods of Moser and Shepherd (2009). A 5 mm incision was made in the abdominal cavity at the midpoint of the pectoral fin on the left side of the fish. In total, handling time lasted no longer than 2 minutes. Black sea bass were released immediately if they were in good condition; fish that appeared weaker were monitored in live wells on board to monitor their recovery for 2-5 minutes. Black sea bass pulled up from deep sampling sites often had extended swim bladders; pressure was released when the incision was made into the abdominal cavity for tagging. Tagged fish that appeared weakened, especially after holding them for >15 minutes were not released. Tag retention rates were determined by holding tagged black sea bass in tanks at the Rutgers University Marine Field Station in Tuckerton, New Jersey.

Black sea bass recaptured by local fishermen were reported by telephone and email. Latitude and longitude of where the fishermen caught the fish were recorded when possible; points of reference and artificial reef name were used if exact location was unavailable. In cases when the fish carcass was available, black sea bass were picked up from fishermen along with the tag. All recaptured fish were checked for signs of sex change by comparing the sex at time of recapture to the fish’s sex when originally tagged and released. If black sea bass carcasses were unavailable, tags were sent via postal service to the Rutgers Marine Field Station.

Data analysis
Since size is related to sex in protogynous hermaphrodites (larger fish tend to be male), analyses of sex selectivity and sex change all account for fish length. Sex selectivity curves were calculated for males and females captured by hook-and-line and trap gear types. Each curve measured the probability that a tagged male or female will be recaptured in either traps or by hook-and-line fishing gear at a given length. For male black sea bass, the total number of tagged males recaptured by hook-and-line and the total number of tagged males recaptured in traps was divided by the total number of tagged males. Similarly, total number of females recaptured by hook-and-line and the total number of females recaptured in traps were divided by the total number of tagged females. Recapture probabilities for males caught by hook-and-line and in
traps, and females caught by hook-and-line and in traps were calculated based on recapture rates within truncated size bins to account for the confounding effects of fish length.

To model (1) the estimated size of when 50% of females change sex and (2) the proportion of male black sea bass captured by both gear types at length involved fitting a generalized linear model using a logit-link function and a binomial error distribution (commonly referred to as logistic regression). When calculating the size at 50% sex change, the response variable was the presence of sex change, \( p(\text{sex change}) = 1 \), or not changing sex, \( p(\text{sex change}) = 0 \). When calculating the proportion of male black sea bass captured at a given length, the response variable was sex (male = 1, female = 0) and gear type was included as a covariate (hook-and-line or trap).

**Results**

Overall, 3,994 black sea bass were sampled in 2011 and 2012 (Table 1, Figure 2). Of these, 2,430 were caught by hook-and-line methods and 1,517 were caught in commercial traps. Total sample sizes for males and females were 1,762 and 1,931, respectively. In 2011, 973 tags and in 2012, 526 tags were deployed across all sampling sites for a total of 1,499 deployed tags. Of all tagged fish, 723 were male and 757 were female. The overall recapture rate was 0.31 (461/1,499), but black sea bass carcasses were turned in for only 308 fish of the 461 tags returned. During sampling we deployed 1,299 orange tags (low reward) and 200 red tags (high reward tags). Recapture rate for orange tags was 0.29 (378/1,298) and for red tags 0.37 (75/200). Based on the difference between high and low reward tags, we expect approximately 20 tagged black sea bass were captured by fishermen but never reported and turned in.

A total of 2,430 black sea bass were caught by hook-and-line gear and 1,517 black sea bass caught in commercial traps (Table 2). Of these, 91 tagged females and 66 males were recaptured by hook-and-line gear. In commercial pots, 34 tagged females and 66 tagged males were recaptured. Overall recapture rates by sex and gear were as follows: females recaptured by hook-and-line 0.12 (91/757), males recaptured by hook-and-line 0.09 (66/723), females recaptured in traps 0.04 (34/757), and males recaptured in traps 0.09 (66/723).

Commercial traps captured a significantly higher proportion of male black sea bass at length and age than the proportion of males captured by hook-and-line gear (\( P < 0.0001 \)) (Figures 3 and 4). The size range of fish caught by each capture method differed. In traps, male fish length ranged from 129 mm to 483 mm, and female body size in traps ranged from 129 – 425 mm (Figure 5). Hook-and-line gear captured a wider size range, males captured by hook-and-line ranged 173 – 533 mm and females ranged 94 mm to 458 mm (Figure 6).

The probability of recapturing male and female black sea bass varied by size, age, and fishing gear (Figure 7 and Table 3). In general, males were more likely to be recaptured over a larger
size range compared to females; recaptured males ranged from 270 mm to 461 mm whereas recaptured females ranged from 250 mm to 383 mm. The probability of recapturing males by size in traps was dome-shaped (Figure 7a) and reached a maximum probability of 0.12 at an intermediate size of 340–360 mm. The recapture selectivity curve for males caught by hook-and-line, however, was asymptotic-shaped and reached a maximum probability of 0.60 when males were 460–480 mm (Figure 7c). Female black sea bass selectivity curves differed from those of male black sea bass (Figure 7b and 7d) The highest probability of recapturing females in traps was 0.12 when females were 380–400 mm; female fish with a body size of 380–400 mm experience a recapture rate of 0.12, this rate is likely artificially inflated because sample sizes were low in this size class. Females caught by hook-and-line gear were most likely to be 260–280 mm; females in this size class experienced a recapture rate of 0.21. Recapture probabilities also varied by age, but sample sizes of recaptured individuals were much lower since many scales collected for age determination were not readable (Table 3).

We observed sex change in eight female black sea bass (Table 4). All sex change events occurred in females 290–370 mm, at the time of recapture newly formed males were 342–480 mm. Sex change occurred from 2011 to 2012, except for one female which was tagged in June, 2011 and recaptured as a male in December, 2011. Of the eight fish that changed sex, five individuals were four years old when they were tagged in 2011 and all of them verified as age five in 2012. One individual was three years old in 2011 and verified as age four in 2012. Scales from the remaining two individuals were unreadable in both 2011 and 2012.

From 2011 to 2012, the overall sex change rate was 47% (+/- 1%) (Figure 7). Uncertainty in the sex change rate was described using the beta distribution which is continuous and bounded from 0 to 1 and frequently used for modeling the probability density of success in binomial data (Bolker 2007). In 2011, 430 females were tagged and of these, 15 were recaptured in 2012 to verify if sex change happened (‘success’) or if females remained female (‘failure’). Of the 15 females tagged in 2011 and recaptured in 2012, 7 were successes and 8 were failures.

Length at 50% sex change occurred at 366 mm (Figure 3.9) based on a logistic regression model of the probability of sex change at length. A total of 114 females were tagged and recaptured throughout 2011 and 2012, 106 remained female and 8 had changed their sex.

Discussion

Limitations of the study
Natural mortality was not accounted for in this study, but it could have an impact on interpretation of recapture rates. The shapes of selectivity curves for female black sea bass caught in traps and by hook-and-line were slightly difficult to interpret because the curves did not follow a smooth pattern. Based on the distribution of female recapture rates, it is difficult to ascertain if the probability of recapture by either commercial traps (Figure 6b) or hook-and-line
gear (Figure 6d) generally increases or decreases with female size. The probability of recapturing females could follow more of a uniform distribution than either asymptotic or dome-shaped, suggesting that females within a certain size range are equally likely to be captured by traps and anglers. Between the two gear types, female black sea bass are slightly more vulnerable to recapture by anglers compared to traps; however, larger sample sizes in select size classes will likely reveal a more continuous selectivity curve that more effectively shows the relationship between female size and catchability for commercial and recreational fishing gears.

**Evidence of sex selectivity**

This study shows clear evidence of sex selectivity in the black sea bass population for commercial and recreational fishing gears. For all size classes, commercial traps captured a significantly higher proportion of male black sea bass compared to the proportion of males captured by hook-and-line fishing gear. The size selectivity curves for male and female black sea bass varied by fishing gear, indicating that commercial and recreational fishing methods are sex selective. For males caught by anglers, the probability of being recaptured increased with size resulting in an asymptotic selectivity curve. Alternatively, male fish caught by commercial traps experienced dome-shaped selectivity, males of an intermediate size range were recaptured the most (260 – 380 mm) compared to hook-and-line gear which was biased toward males 260 – 533 mm. Both gears, traps and hook-and-line, targeted female black sea bass of a narrower size range and gear bias followed different selectivity curves compared to male black sea bass.

This is the first time sex selectivity has been directly measured in black sea bass or any other exploited protogynous grouper. The occurrence of sex selectivity, however, is not a new phenomenon and has been documented in other fisheries around the world. For example, in Japan protandrous pandalid shrimps (Pandalidae, *Pandalus*) (male to female sex change) the sex ratio is increasingly biased toward males throughout the commercial fishing season (Chiba et al. 2013). Harvested shrimp, however, were found to be 98% female because fishing methods were heavily selective of females. In the United Kingdom, sex ratios in perch (*Perca fluviatilis*) shifted dramatically in favor of females over six decades in response to strong selectivity of mature males (Langangen et al. 2011). In pandalid shrimps, perch, and others (Goni et al. 2001, Kendall and Quinn 2013), males and females experience differences in catchability that is often mediated by size selectivity in species that are drastically sexually dimorphic.

In exploited black sea bass populations, however, and potentially other protogynous groupers with similar life histories, sex-specific behavior patterns may play an important part of sex selective fishing patterns. For passive fishing methods, such as traps and hooks, behavior becomes even more important because individual fish must choose to enter the trap or lunge, attack, and bite a hook; a decision that could be influenced by the presence of nearby individuals (Jivoff and Hines 1998, Smith et al. 2004). Protogynous fish species are known to develop complex social structures during the reproductive season (Robertson 1972, Myoer and Nakazono
Large males are particularly aggressive because they are actively courting, defending, and competing for female mates (Myoer and Nakazono 1978, Warner and Swearer 1991, Mumby and Wabnitz 2002, Kline et al. 2011). Since black sea bass are hermaphrodites (Benton and Berlinksy 2006), large males are expected to display similar patterns of aggressive behavior throughout the spawning season. Aggressive fish are particularly vulnerable to passive fishing gears (Sutter et al. 2012, Biro and Post 2008), and it is likely that behavior of fish, more so than body size, determines a fish’s vulnerability to capture in passively operated fishing gears (Uusi-Heikkila et al. 2008). Aggressive behavior among large male black sea bass could explain why selectivity of males was not only higher than females, but also covered a wider range of body sizes, especially for hook-and-line fishing gear.

Large male black sea bass were more likely to be recaptured by hook-and-line than by traps; this observation has two possible explanations. From the design of traps employed in our study and our observation that, it is apparent that very large black sea bass may be less likely to enter the trap than medium and small individuals, an observation seen in other species (Hepper 1977). Hook-and-line gear does not impose obvious size limits on capturing fish, so long as a fish’s gape can accommodate the hook passing into the mouth. The difference in gear design suggests that it is expected the sampling bias of each gear will follow different selectivity curves (Miller and Fryer 1999). The second explanation is one related to sex-specific behavior rather than size. Differences in sex-specific behavior could make it more or less likely that individuals will enter traps. This was observed in crabs (Callinectes sapidus and Portunus pelagicus) when immature females would be likely to avoid entering traps with mature males (Jivoff and Hines 1998, Smith et al. 2004). Social interactions between males and females of protogynous species can be constructed through complicated hierarchal networks (Sakai et al. 2003); where depending on rank within the social structure males engage in interaction (Kroon et al. 2000). Not enough information is known about male- and female-specific roles within black sea bass social structure to be certain that behavior, rather than size, is the reason for why large males are not as likely to be recaptured by traps as they are by hook-and-line.

Hook-and-line fishing gear was biased toward catching large male black sea bass, an observation that may be explained by high energetic demands of large, aggressive fish. Individuals that expend more energy through aggressive swimming, defending territories, competing for reproductive opportunities and have fast growth rates require a high intake of energy to sustain such behavior. Hook-and-line fishing gear depends on the willingness of a fish to lunge at a hook and the fish’s effectiveness at ‘catching’ the baited hook; aggressive and fast growing individuals have higher energy demands and will attack baited hooks more frequently than less aggressive individuals (Sutter et al. 2012, Biro and Post 2008). Aggression is associated with fish of larger body size in protogynous hermaphrodites (Moyer and Nakazono 1978, Warner and Swearer 1991, Kline et al. 2011), which could explain why large males were most likely to be recaptured by hook-and-line. There is evidence that protogynous hermaphrodites follow sex-specific growth
rates and that recently sex-changed males in protogynous fish species undergo a spurt of growth to ensure their dominance among competing males and large females (Garrett et al. 1993, Munday et al. 2004). If sex-changing black sea bass grow particularly fast, then it would be expected their energetic demands would out-weight females, suggesting large males may be more likely to attack baited hooks.

Sex-specific migratory patterns have led to sex selective fishing in some fisheries (Goñi et al. 2001, Gerritsen et al. 2010), but is not likely the reason for sex selectivity in black sea bass. Trap efficiency of Mediterranean spiny lobster (Palinurus elephas), for example, differed for males and females throughout the fishing season because females would move to deeper depths throughout the season which is coordinated with male moulting behavior (Goñi et al. 2001). Observations of protogynous species suggest sex-specific migrations; in E. guttatus (Sadovy et al. 1994) and M. microlepis (Coleman et al. 1996) in the Gulf of Mexico and U.S. Virgin Islands, males and females co-occur only during the spawning season which is January through February. During other parts of the year, E. guttatus and M. microlepis females remain in shallow warm waters near shore and males dwell in deep, colder waters offshore. If male and female black sea bass separate spatially, similar to other protogynous groupers (Sadovy et al. 1994, Coleman et al. 1996), and if commercial fishing traps are more often placed in male-dominated habitats, then we would expect traps to capture higher proportions of male fish because females would not be in the vicinity. In black sea bass, however, sex-specific migratory patterns probably do not explain the sex-selectivity observed by commercial and recreational fishing methods. In this study, hook-and-line sampling and the deployment of traps were conducted at the same sites in order to sample from the same population. Large scale migrations just before and after the reproductive season may be sex-specific, but throughout our sampling period which corresponded with the reproductive season sex-specific habitats seem unlikely.

**Sex change as a function of size, age, and season**

Sex change occurred in female black sea bass ages 3 – 4 years (290 – 370 mm) turning 4 – 5 years (342 – 480 mm). Fifty percent of female black sea bass were expected to change sex when body size was 365 mm. Male black sea bass were present in all age classes from one through eight. Sex change among females, as a function of season, occurred between annual spawning seasons, and slightly less than half (47%) of female black sea bass in 2011 were expected to change sex by 2012.

Previous studies of protogynous hermaphrodites show that the periodicity of sex change throughout the year is highly variable among species (Wenner et al. 1986, Shapiro et al. 1993, Burgos et al. 2007). Transition individuals were found year-round in red hind (Shapiro et al. 1993), whereas in South Atlantic black sea bass transitioning individuals were only observed during a 2-3 month window immediately following the spawning season (Wenner et al. 1986). Transitioning individuals are thought to be not reproductively functional, which explains why
fish actively reversing their sex are found outside of the spawning season (Wenner et al. 1986, Shapiro et al. 1993, Burgos et al. 2007). In California sheephead (*Semicossyphus pulcher*) however, this pattern does not follow since 21% of fish sampled during the spawning season were in sexual transition (Loke-Smith et al. 2011). The timing of sexual transition in relation to spawning season, a relationship which might be able to predict when fish are expected to change sex, is also variable among fish species. Black sea bass in the South Atlantic in transition were found within a 2-3 month period after the major and minor spawning seasons (Wenner et al. 1986), but red hind in transition were found throughout the year even though spawning occurs within a narrow, one month window in early February (Shapiro et al. 1993). The periodicity of individuals in transition clearly varies among species, these studies, however, were not able to predict the prevalence of sex change; i.e. how many females are expected to change sex in population over a specific time.

Knowing the prevalence of sex change within a population has implications on stock assessment (Alonzo et al. 2008). By incorporating the overall rate of sex change in population dynamics models, the loss of female spawning biomass and addition of mature male biomass can be accounted for annually. Failing to track the amount of biomass shifting from female to male can lead to an overestimation of spawning biomass (Alonzo et al. 2008). Given the biological and ecological complexity of sex change, the rate of sex reversal is most likely species- and possibly population-specific. In black sea bass in central New Jersey, approximately 47% of females were expected to become male by 2012. To estimate sex change rate in other hermaphroditic species, mark-recapture experiments will need to be implemented to track which individuals change and do not change sex.

In conclusion, black sea bass in the Mid-Atlantic Bight are currently exposed to sex selective fishing pressures. Males and females of similar sizes experience different rates of catchability, sex selectivity could be caused by a combination of sex-specific behavior and size selectivity on sexually dimorphic individuals. Selectivity also varied by fishing method, suggesting that different commercial and recreational fishing gears impose unique sampling biases on the black sea bass population. Since black sea bass are protogynous hermaphrodites, it is important to quantify the annual rate of sex change in population for stock assessment purposes. In our study, slightly less than half (47%) of females in 2011 were expected to change sex by 2012. These results have implications for stock assessment, as well as highlight the importance of learning more about the social structure and patterns of sexual transition in black sea bass in order to better understand the effect fishing has on sex changing species.
Table 1. A summary of black sea bass tagging data in southern New Jersey in 2011 and 2012. Total recapture rate includes individuals that have been recaptured more than once; of the 461 recaptures, 29 of these were recaptured more than once. Male and female recapture rates do not include recaptured fish submitted through the tag-return program for which only a tag was returned (153 tags were submitted without the black sea bass carcass). In these cases, either the carcass was disposed by the fishermen or the tag was cut and the fish released back into the ocean.

<table>
<thead>
<tr>
<th>Tagged BSB</th>
<th>Recapture rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total BSB caught = 3,994 (1,499 tagged)</td>
<td>Male = 723</td>
</tr>
<tr>
<td></td>
<td>Male = 18.1% (n=133)</td>
</tr>
<tr>
<td></td>
<td>Red tag = 37.5% (n=75/200)</td>
</tr>
<tr>
<td>Total recapture rate = 30.7% (n = 461)</td>
<td>Female = 757</td>
</tr>
<tr>
<td></td>
<td>Female = 16.4% (n=124)</td>
</tr>
<tr>
<td></td>
<td>Orange tag = 29.1% (n=378/1298)</td>
</tr>
</tbody>
</table>
Table 2. Summary of black sea bass recapture rates caught by two different gear types. Black sea bass were sampled in May-October of 2011 and 2012.

<table>
<thead>
<tr>
<th>Gear type</th>
<th>Total captured</th>
<th>Recapture by sex (number tagged)</th>
<th>Recapture rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traps</td>
<td>1,517</td>
<td>Male = 66 (723) Female = 34 (757)</td>
<td>0.09 0.04</td>
</tr>
<tr>
<td>Angling</td>
<td>2,430</td>
<td>Male = 66 (723) Female = 91 (757)</td>
<td>0.09 0.12</td>
</tr>
</tbody>
</table>
Table 3. Summary of male and female recapture rate in traps and by hook-and-line. Sample sizes include: 4 tagged females recaptured by traps, 7 tagged males recaptured by traps, 13 tagged females recaptured by hook-and-line, and 5 tagged males recaptured by hook-and-line. Samples were lower than sample sizes for recapture rates of males and females by length because a portion of scales pressed for age determination were not readable.

<table>
<thead>
<tr>
<th>Age</th>
<th>Traps Male (n=7/497)</th>
<th>Traps Female (n=4/552)</th>
<th>Hook-and-line Male (n=5/497)</th>
<th>Hook-and-line Female (n=13/552)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0</td>
<td>0.01</td>
<td>0.007</td>
<td>0.017</td>
</tr>
<tr>
<td>3</td>
<td>0.023</td>
<td>0.004</td>
<td>0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>4</td>
<td>0.009</td>
<td>0.01</td>
<td>0.009</td>
<td>0.03</td>
</tr>
<tr>
<td>5</td>
<td>0.063</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 4. Summary of black sea bass that changed sex in 2011 and 2012. Wild black sea bass that were female at first captured (date when tagged) and later recaptured as male (recapture date).

<table>
<thead>
<tr>
<th>Fish ID</th>
<th>Date when tagged</th>
<th>Recapture date</th>
<th>Days at large</th>
<th>Age (at tagging)</th>
<th>Growth (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>00701</td>
<td>8/24/2011</td>
<td>5/27/2012</td>
<td>277</td>
<td>4</td>
<td>57</td>
</tr>
<tr>
<td>00431</td>
<td>7/13/2011</td>
<td>5/26/2012</td>
<td>318</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>00698</td>
<td>8/24/2011</td>
<td>8/22/2012</td>
<td>364 Scale not aged (omit)</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>00453</td>
<td>7/13/2011</td>
<td>8/6/2012</td>
<td>390 not aged yet</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>00161</td>
<td>6/3/2011</td>
<td>7/13/2012</td>
<td>406</td>
<td>4</td>
<td>77</td>
</tr>
<tr>
<td>01339</td>
<td>6/9/2011</td>
<td>8/12/2012</td>
<td>430</td>
<td>3</td>
<td>173</td>
</tr>
</tbody>
</table>
Figure 1. Contrasting the difference between asymptotic and dome-shaped selectivity curves. A simulated example showing (a) age distribution in the catch, as well as two different selectivity curves: (b) a percent saturation curve with age where the oldest size classes are fully selected and (c) a dome-shaped selectivity curve where vulnerability is lowest at very young and old age classes. The assumed population structure under saturation selectivity curves (d) and dome-shaped selectivity curves (e).

Figure 2. Size distribution and frequency of black sea bass caught by traps and hook-and-line gear. Size distribution of black sea bass caught in commercial pots (orange bars) and caught by recreational hook and line gear (blue bars). Black sea bass caught in commercial pots ranged in size from 129 – 483 mm, black sea bass caught by hook-and-line gear ranged in size from 94 – 533 mm. Sample size for each gear was 2,430 by angling and 1,517 by potting.

Figure 3. The proportion male of wild black sea bass caught in commercial traps and by recreational hook-and-line gears. The orange line represents males caught in traps and the blue line represents males caught by recreational hook-and-line. The difference between the proportion male caught in traps and the proportion caught by angling at size was highly significant ($P < 0.0001$). Circle size is proportional to number of observations at a given integer length. Sample sizes for traps and angling was 1,517 and 2,430, respectively.

Figure 4. Proportion male at age caught by traps and hook-and-line. The proportion of male black sea bass caught at age by hook-and-line fishing gear (thin line) compared with the proportion male caught at age by commercial traps (thick line).
Figure 5. Size distribution and frequency of male (red bars) and female (green bars) black sea bass caught in commercial traps. Female size distribution is overlaid on top of male size distribution (male distribution is behind). Minimum size limit in the commercial fishery is 280 mm (indicated by solid black line). Males caught in commercial trap ranged in size from 129 – 483 mm, female black sea bass caught in pots ranged in size from 129 – 425 mm.

Figure 6. Size distribution and frequency of male (red bars) and female (green bars) black sea bass caught by hook and line gear. Male size distribution is overlaid on top of female distribution (female distribution is behind). The minimum size limit in the recreational fishery is 317 mm (indicated by solid black line). Males caught by hook and line gear ranged in size from 173 – 533 mm, female black sea bass caught in pots ranged in size from 94 – 458 mm.

Figure 7. The probability of recapturing wild black sea bass by size, sex, and gear. The probability of recapturing (a) males in traps, (b) females in traps, (c) males by hook-and-line, and (d) females-by-hook and line. Dashed lines indicate the fishery’s minimum size limit. A total of 723 and 757 male and female black sea bass were tagged in 2011 and 2012, respectively. Sample sizes of recaptured black sea bass included: 66 males were recaptured in traps, 66 males were recaptured by hook-and-line; 34 females were recaptured in traps; and 91 females were recaptured by hook-and-line. *Low sample sizes. In (c), starred bar on left had 3 of 5 (60%) tagged BSB recaptured and starred bar on right had 1 of 1 (100%) tagged BSB recaptured. In (d) starred bar had 1 of 1 (100%) tagged BSB recaptured.

Figure 8. Probability of female black sea bass changing sex from 2011 to 2012. Probability density function for the probability of sex change (female to male) for individuals released
in one year (2011) and recaptured the following year (2012). A total of 430 females were tagged in 2011; of these, 15 individuals were recaptured in 2012. Seven of the 15 recaptures had changed sex to male since 2011 and the remaining 8 were still female when recaptured.

Figure 9. Probability of sex change at length in wild black sea bass. Length at 50% sex change is 366 mm. Sample size includes all black sea bass that were female when first tagged and recaptured later to verify sex change. Of these, 114 females remained female when recaptured and 8 females were recaptured as males.
Figure 2

All fish captured
(blue=angling)
(orange=potting)
Figure 3

Proportion male

Length (mm)

Orange = Potting
Blue = Angling
Figure 4
Figure 5

BSB captured in pots
(male = red)
(female = green)
Figure 6

BSB captured by angling
(male = red)
(female = green)
Figure 7

(a) 

(b) 

(c) 

(d)
Figure 8

probability density
0.0 1.0 2.0 3.0

p(being male next year)
0.0 0.2 0.4 0.6 0.8 1.0

beta(8,9)
mean=0.47 +/- 0.01
Figure 9

![Graph showing the probability of sex change against length (mm) with n=114.](image)
References
California sheephead, Semicossyphus pulcher (Pisces : Labridae). *Environmental Biology of Fishes* 71,

sperm limitation in sex-changing fish. *Fishery Bulletin* 102, 1-13. doi:

spawning-per-recruit measures in protogynous stocks. *Fishery Bulletin* 103, 229-245. doi:

protogynous sex change into stock assessments. *Bulletin of Marine Science* 83, 163-179. doi:

doi:

69, 1491-1503. doi: 10.1111/j.1095-8649.2006.01212.x


precedes the decrease in brain aromatase activity during socially mediated sex change in *Lythrypnus dalli*.


Gulf of Mexico. *Journal of Fish Biology* 63, 1505-1520. doi: 10.1046/j.1095-8649.2003.00263.x


**Electronic articles**
