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Spatial and temporal patterns of abundance of juvenile black sea bass (*Centropristis striata*) in Maryland coastal bays

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Abstract—Black sea bass (*Centropristis striata*) is a warm temperate species that is associated with structured habitats along the U.S. Atlantic coast and Gulf of Mexico. The northern stock is considered data poor, and the lack of information on the life history, especially at the juvenile stage, is a concern. We analyzed trawl survey data collected during 1989–2013 from the Maryland coastal bays (MCBs) by the Maryland Department of Natural Resources, and used catch-per-unit-of-effort (CPUE) to determine spatial and temporal patterns in abundance of black sea bass. The highest CPUE occurred at sites close to the MCBs inlets, suggesting the presence of suitable habitats for this species in these areas. Spatial patterns of abundance of black sea bass showed no consistent relationship with temperature, salinity, dissolved oxygen, and Secchi disk depth, a measure of water transparency ($P>0.05$), but CPUE was positively correlated with water depth ($P=0.025$). Average growth rate of the fish was 0.58 mm total length (TL)/day, ranging from 0.46 to 0.72 mm TL/day. Results of a generalized linear model with a Poisson distribution indicated that salinity and the North Atlantic Oscillation index best predicted interannual variation in CPUE of age-0 fish, but not CPUE of age-1 black sea bass. Information from this study can be used to form a basis for future studies in the coastal bays of Maryland and other coastal lagoon systems.

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Estuaries on the Atlantic and Gulf coasts of the United States serve as nursery areas for many commercially and recreationally harvested fish species. However, some smaller estuaries throughout this region are relatively understudied, resulting in a limited understanding of how important they are as habitats for some marine fish species. This lack of information causes difficulties for the protection of nursery areas of a particular species (Beck et al., 2001). One such species is the black sea bass (*Centropristis striata*), which is currently considered data poor owing in part to its protogynous hermaphroditic nature (Able et al., 1995; Shepherd[1]).

The black sea bass is a temperate fish species that occupies an extensive range from the Gulf of Maine to the Gulf of Mexico (Steimle et al., 1999). It is commercially and recreationally harvested throughout its range, requiring management by state and federal fishery management agencies. Because of the large extent of its range, the black sea bass is managed as 3 stocks: the northern, southern, and Gulf of Mexico stocks, which have differences in migratory behavior and genetic makeup (Steimle et al., 1999). The northern stock, from the Gulf of Maine to north of Cape Hatteras, North Carolina, is seasonally migratory, occupying coastal habitats in warmer months and moving offshore to areas along the continental shelf for the winter (Musick and Mercer, 1977; Drohan et al., 2007; Moser and Shepherd, 2009). While in their coastal habitats, adults spawn from April to November, and peak spawning occurs between June and September (Able et al., 1995). Spawning begins earlier in southern areas of the stock, with the earliest larvae found during March off North Carolina, but later in July off New Jersey (Able et al., 1995). Young-of-the-year (YOY) black sea bass may enter estuaries from July until September at total lengths (TLs) of roughly 13–24 mm (Musick and Mercer, 1977), but they can enter as early as March in southern areas near Virginia (Kimmel, 1973). The differences in habitat use of YOY and adult black sea bass, along with differences in timing of spawning and migration into estuarine habitats (Drohan et al., 2007), make it necessary for age-specific and

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[1] Shepherd, G. R. 2009. Black sea bass. *In* The Northeast Data Poor Stocks Working Group report, December 8–12, 2008 Meeting. Part A. Skate species complex, deep sea red crab, Atlantic wolffish, scup, and black sea bass. Northeast Fish. Sci. Cent. Ref. Doc. 09-02A&B, p. 423–463. [Available from website.]

estuary-specific studies to be conducted to provide effective information for management of this species.

Young-of-the-year and age-1+ black sea bass are captured in estuarine habitats during the warmer months of the year when the northern stock occupies inshore areas of the continental shelf. Studies of juvenile black sea bass have been conducted in a few estuaries in their northern range, especially with regard to their distribution, abundance, growth, habitat fidelity, and feeding habits (Richards, 1963; Kimmel, 1973; Allen et al., 1978; Festa[2]; Heck and Orth, 1980; Werme, 1981). The species has been reported (see Steimle et al., 1999) in various estuaries in the Mid-Atlantic Bight, such as southern Chincoteague Bay, Virginia (Schwartz, 1961), Magothy Bay, Virginia (Kimmel, 1973), central Long Island Sound (Richards, 1963), Raritan and Sandy Hook Bays (Wilk et al.[3]) and Barnegat Bay, New Jersey (Tatham et al., 1984). The preferred estuarine nursery habitats are shallow areas with structure that can serve as a refuge from predators (Steimle et al., 1999). While in estuaries they exhibit site fidelity (Able and Hales, 1997) and can be found around bridge pilings, rock jetties, artificial reefs, and oyster reefs along with seagrass beds (Steimle et al., 1999). During this time, black sea bass grow rapidly at a rate of 0.74 mm TL/day during the summer (Able and Hales, 1997). Little growth occurs during their overwintering time offshore, and 95% of black sea bass are mature at around 28 cm TL (length at 50% maturity occurring at 20.4 cm [Shepherd and Nieland[4]]). Because of the possibility of size selective overwinter mortality, the time black sea bass spend in estuaries is vital to their growth, survival, and subsequent recruitment to the adult population.

Information on the ecology of black sea bass in Maryland coastal bays (MCBs), the series of 5 bays located on the eastern shore of Maryland, is scarce. Such information is needed to assess the extent to which the MCBs serve as nursery habitats for black sea bass and contribute to the adult population in the coastal ocean. In 2013 Maryland accounted for 11% of the 984.30 metric tons (2.17 million lb) commercial catch quota and 19.14 of the 598.74 metric tons (or 42,200 lb of the 1.32 million lb) of total allowable landings for recreational harvest (Butowski et al.[5]), hence estuaries in the Maryland area including the MCBs may be important nursery grounds for black sea bass.

The Maryland Department of Natural Resources conducts the Coastal Bays Fisheries Investigations Trawl and Beach Seine Survey in the MCBs to assess trends in juvenile fish abundance (Butowski et al.[4]). This survey takes place monthly from April to October each year at 20 fixed sites, and was standardized in 1989 (Pincin et al., 2014). The data from these surveys have been used to examine trends in abundance and distribution of juveniles for some finfish and crab species (Murphy and Secor, 2006; Love et al., 2009; O'Brien, 2013; Pincin et al., 2014; Malagon, 2015) but not for the black sea bass. A recent study showed that the indices of abundance of juvenile black sea bass determined from the NOAA Northeast Fisheries Science Center trawl surveys in the mid-Atlantic were highly correlated with indices of abundance from independent surveys conducted by a number of state agencies (Miller et al., 2016). This finding suggests that data from trawl surveys may be useful for describing seasonal, as well as interannual, variations in the abundance of black sea bass in estuaries such as those in the MCBs.

The objectives for this study were 1) to describe spatial and seasonal changes in the abundance and size composition of black sea bass, and assess the role of environmental factors in the spatial distribution pattern, and 2) to evaluate the influence of environmental (temperature and salinity) factors and major climatic phenomena, such as the North Atlantic Oscillation (NAO) and El Niño Southern Oscillation (ENSO) events, and the influence of spawning stock biomass of black sea bass on the recruitment dynamics of juvenile black sea bass. Previous studies have shown that the NAO affects other species in the northwest Atlantic. For example, abundance of the northern shortfin squid (*Illex illecebrosus*) was found to be higher in years with a negative NAO index, which provides weak winter northwesterly winds (Dawe et al., 2000). Other similar studies, found that NAO affected the recruitment of Atlantic cod (*Gadus morhua*) in European waters, especially when spawning stock biomass was low (Brander, 2005), and contributed to the decline of the northern stock of Atlantic cod off of Canada (Mann and Drinkwater, 1994; Parsons and Lear, 2001). Understanding the role that climatic factors have in recruitment into nursery areas for economically valuable species is important for the future management of the stocks, particularly as management moves toward ecosystem-based management.

Materials and methods

Study location

The MCBs located on the eastern shore of Maryland and separated from the Atlantic Ocean by 2 barrier Islands (Pincin et al., 2014) are composed of 5 bays: Assawoman, Isle of Wight, Sinepuxent, Newport, and Chincoteague

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[2] Festa, P. J. 1979. Analysis of the fish forage base in the Little Egg Harbor Estuary. New Jersey Department of Environmental Protection, Division of Fish Game and Shellfish, Bureau of Fisheries, Nacote Creek Station, Tech. Rep. 24M, 134 p. [Available from website.]

[3] Wilk, S. J., E. M. MacHaffie, D. G. McMillan, A. J. Pacheco, R. A. Pikanowski, and L. L. Stehlik. 1996. Fish, megainvertebrates, and associated hydrographic observations collected in the Hudson-Raritan Estuary, January 1992–December 1993. Northeast Fish. Sci. Cent. Ref. Doc. 96-14, 95 p. [Available from website.]

[4] Shepherd, G. R., and J. Nieland. 2010. Black sea bass 2010 stock assessment update. Northeast Fish. Sci. Cent. Ref. Doc. 10–13, 25 p. [Available from website.]

[5] Butowski, N., R. Morin, and M. Topolski. 2013. 2012 Fishery management plan: report to the legislative committees, 185 p. Maryland Dep. Nat. Resour., Fish. Serv., Annapolis, MD. [Available from website.]

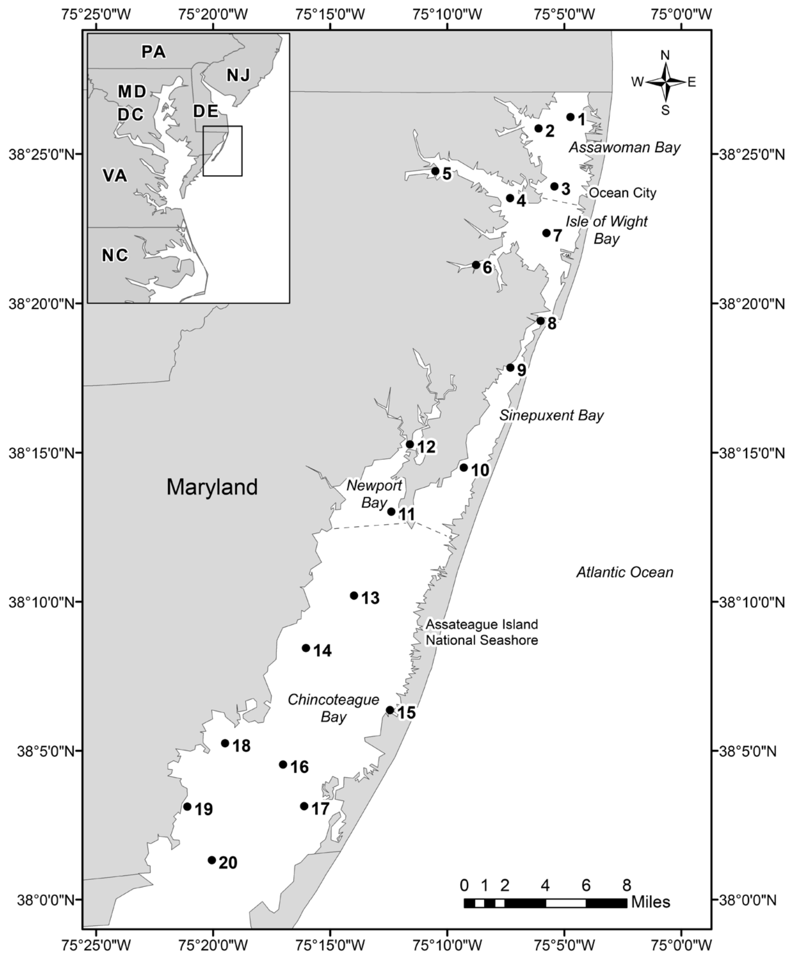

Figure 1

Map showing the 20 sites sampled for the Maryland Department of Natural Resources' Coastal Bays Fisheries Investigations Trawl and Beach Seine Survey in Maryland coastal bays.

Bay (Fig. 1). The northern bays (area north of the Ocean City Inlet) are Assawoman and Isle of Wight Bay, and the southern bays (area south of the Ocean City Inlet) are Newport Bay, Sinepuxent, and Chincoteague Bay (Fig. 1). The MCBs are one of the most diverse estuaries on the east coast (U.S. EPA, 2006). The system covers about 453 km^2 and supports many species including finfish, mollusks, crustaceans, birds, and mammals (ANEP[6]). Groundwater is the primary source of freshwater flow into the bays (Wazniak et al., 2004a); salinities are high in the bays except in areas upstream in the tributary rivers and creeks (Wazniak et al., 2004b). Flushing is slow because of limited tidal exchange between the bays and the ocean through the Ocean City and Chincoteague Inlets, and circulation is limited by wind (Wazniak et al., 2004b). The Ocean City Inlet was opened as a corridor by a hurricane in 1933 and has been kept open as a navigation channel by 2 rock jetties along its north and south banks (Wazniak et al., 2004a).

The coastal bays are a tourist attraction, bringing more than 11 million visitors annually to the Eastern Shore of Maryland (MCBP[7]). This high level of use has caused the bays to degrade over time, lowering water quality and resulting in a current overall condition rating of "Moderate," a C+ rating on a multiagency report card which is used to track the health of the MCB ecosystem and is updated annually (IAN, 2015). There is evidence that the abundance of forage fish has declined in the lagoons over the past 20 years (Casey et al.[8]; Pincin et al., 2014), suggesting that fish populations in the MCBs are changing and require further investigations.

Sampling and data analysis

The Maryland Department of Natural Resources Coastal Bays Fisheries Investigations Trawl and Beach Seine Survey is conducted annually at 20 fixed locations that are sampled once a month in the MCBs (Fig. 1) from April until October. The gear used is a 4.9-m semiballoon trawl with 3.18 cm mesh in the outer net, 1.27 cm of mesh in the inner liner, and 2.86 cm of mesh in the codend; a tickler chain is used, and trawling duration at each of the 20 sites was 6 min (Bolinger et al.[9]). Along with numbers of black sea bass at each site, abiotic factors were recorded, including water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), salinity, Secchi disk depth (centimeters), and water depth (meters). The time series of data collected from 1989 to 2013 was used to assess the spatial and temporal changes in abundance of black sea bass.

Catch-per-unit-of-effort (CPUE) was used as an indicator of abundance for black sea bass (Bolinger et al.[8]),

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[6] NEP (Association of National Estuary Programs). 2001. Maryland Coastal Bays. Fact Card. [Available from Maryland Coastal Bays Program, 8219 Stephen Decatur Hwy. Berlin, MD 21811.]

[7] MCBP (Maryland Coastal Bays Program). 2017. Mission and history. Maryland Dep. Nat. Resour., Annapolis, MD. [Available from website, accessed July 2017.]

[8] Casey, J. F., S. B. Doctor, and A. E. Wesche. 2001. Investigation of Maryland's Atlantic Ocean and Coastal Bay Finfish Stocks, 28 p. Federal Aid Project No. F-50-R. [Available from Maryland Dep. Nat. Resour., Fish. Serv., Tawes State Office, Bldg. 2, 580 Taylor Ave., Annapolis, MD.]

[9] Bolinger, A., S. Doctor, A. Luettel, M. Luisi, and G. Tyler. 2007. Investigation of Maryland's coastal bays and Atlantic Ocean finfish stock: 2007 report, 153 p. Federal Aid Project No. F-50-R-16. Maryland Dep. Nat. Resour., Fish. Serv., Annapolis, MD.. [Available from website.]

and was calculated as the number of black sea bass caught divided by the number of tows. CPUE was calculated for each year, month, and site, and was used to evaluate patterns in temporal and spatial abundance. To determine whether any of the abiotic factors recorded in the survey influence spatial distribution of black sea bass in the MCBs, generalized linear models (GLMs) with a quasi-Poisson distribution due to over dispersion, were run for each month. The abiotic factors used in the GLMs were water temperature, dissolved oxygen, salinity, and Secchi disk depth because analyses of variance determined that these factors varied between sites and months. Water depth was not used in each monthly GLM because it did not vary at sites between months. For the monthly models, number of fish at each of the 20 sampling sites was used as the dependent variable, and abiotic variables were used as the predictor variables. A separate regression analysis was run with total CPUE at each site (from 1990 to 2012) as the dependent variable and average depth (in meters) at each site (from 1990 to 2012) as the predictor variable. All statistical analyses were run in R statistical software (vers. 3.2.0; R Core Team, 2015).

Because previous studies found that YOY black sea bass enter estuaries from July to September (Able et al., 1995), 1 January was determined to be the birth date and fish caught during April and May the following year were assumed to be age 1 (juveniles) (Able et al., 1995). Fish length frequencies were examined each month and the 2 standard deviations greater and less than the mode were used to distinguish between year classes (Gulland and Rosenberg, 1992). Black sea bass less than 2 standard deviations of the mode were designated as age 0, and those greater than 2 standard deviations were considered age 1+. The CPUE of YOY fish, used as a recruitment index, was examined in relation to abiotic factors (temperature and salinity), climatic events (annual NAO index, NAO winter, spring, and summer indices, ENSO index, ENSO winter and spring indices, which were calculated and downloaded from the NOAA Climate Prediction Center; website, accessed April 2015), and spawning stock biomass of black sea bass, the latter of which was provided by the Northeast Fisheries Science Center. For this analysis, only data from 1990 to 2012 were used because those were the years with full records of environmental factors measured at each site for each month. A GLM with a Poisson distribution (R Core Team, 2015) was used in a stepwise approach to determine which model and variables best predict recruitment of YOY black sea bass. The model with the lowest Akaike information criterion (AIC) value was chosen as the best indicator for predicting recruitment.

Growth rate of juvenile (age 1) black sea bass was also assessed for years when, at least, 5 black sea bass individuals were captured in May, and in September. Length of black sea bass (TL in millimeters) in May was averaged and subtracted from the average length in September, and the value was then divided by the total number of days over that time period (May–September) (n=152) to estimate growth rates (mm per day) for each year (Tucker, 2000). These values were then averaged together to estimate absolute growth rate of juvenile black sea bass in the MCBs. Regression analysis was then performed to determine whether growth rates were related to abundance or temperature.

Results

Size composition and growth of black sea bass in Maryland coastal bays

The length-frequency distributions of fish collected each month (April–October) from 1989 to 2013 are presented in Figure 2. Trawl catches consisted mostly of age-1 fish; however a few age-0 black sea bass were caught. Black sea bass began to enter MCBs in April in low numbers at sizes ranging from 45 to 95 mm TL. In June they began to enter in higher numbers at sizes of 27 to 205 mm. By October, they had attained sizes of about 58–240 mm TL. Samples collected in April showed the presence of fish that were approximately 1 year old that had entered the MCBs from the coastal ocean. The size range of these fish was similar to the size range of YOY fish captured in October of the previous year, suggesting there was minimal growth during the winter.

Growth rate of age-1 black sea bass from May to September was fastest in 1992 (0.72 mm TL/day) and slowest in 1990 and 2002 (0.46 mm TL/day) and averaged 0.58 mm TL/day. Growth rate had no correlation (P>0.05) with average temperature and abundance data for each year.

Interannual variation in abundance of black sea bass

CPUE of age-1 black sea bass showed no significant increasing or decreasing trend over time (Fig. 3A) but was characterized by low values in 1989, 1993, 1996, 1998, 2004 and 2005 and by the highest CPUE in 2008. In contrast, CPUE of age-0 fish showed a significant annual increasing trend (P<0.05) during 1989–2013, although it also exhibited fluctuations in relative abundance between years. The largest CPUE occurred in 2002, 2008, and 2013, whereas the lowest CPUE was observed in 1989, 1990, 1993 and 1996 (Fig. 3B). The patterns in CPUE of age-1 and age-0 black sea bass over time were somewhat similar, with peak abundances occurring in similar years.

Spatial distribution of black sea bass in Maryland coastal bays

On average from 1989 to 2013, mean CPUE was relatively low at a site (site 5) in the St. Martin River, and at 4 sites (sites 13, 14, 15, 18) in the central part of Chincoteague Bay (Fig. 4). In May, black sea bass were most abundant in the southernmost site located by the Maryland/Virginia border in Chincoteague Bay (Fig.

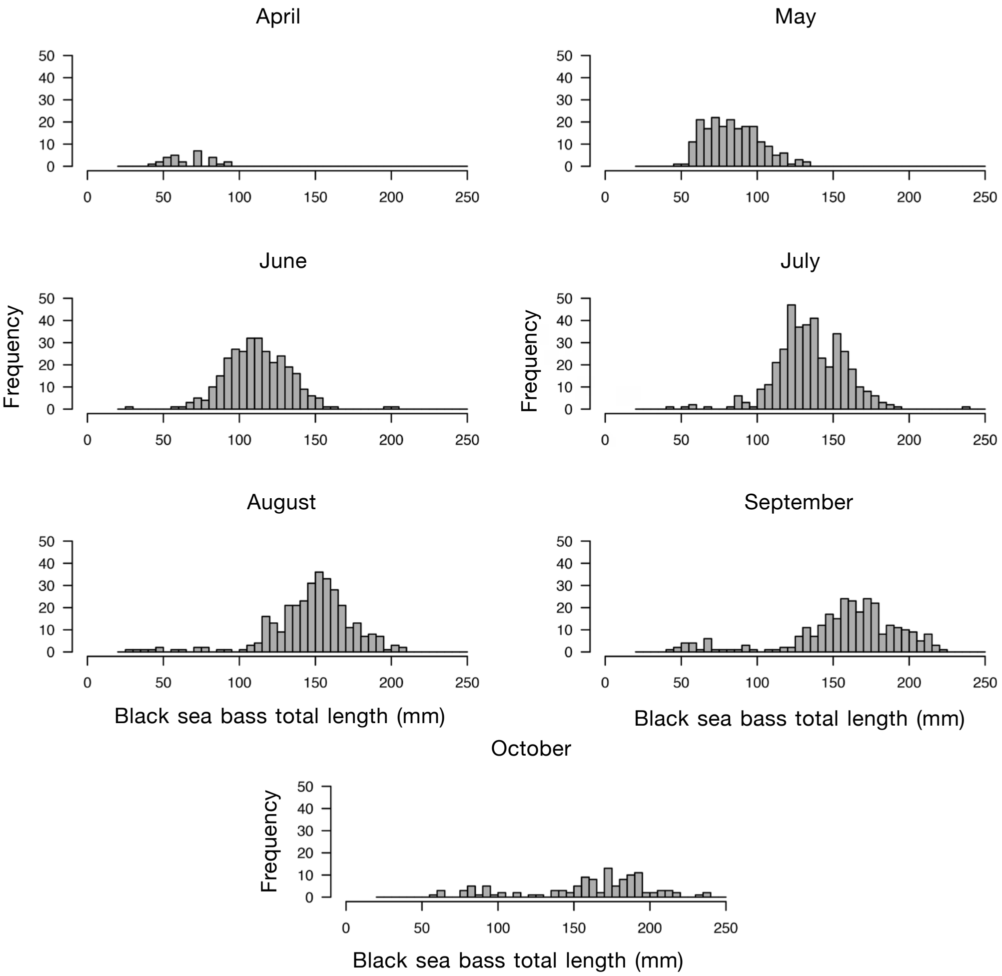

Figure 2

Total-length-frequency distributions of black sea bass (*Centropristis striata*) caught in trawl surveys conducted in Maryland coastal bays by the Maryland Department of Natural Resources during 1989–2013.

5). As temperatures began to warm, black sea bass became more abundant in July in the MCBs, especially in the northern bays. Toward September and October when water temperature began to decrease, black sea bass began to concentrate at sites relatively close to Ocean City and Chincoteague Inlets (Fig. 5).

Results from the GLMs for April, June, August, September and October, showed that temperature, salinity, dissolved oxygen, and Secchi disk depth were not significant predictor variables for catch of black sea bass at the 20 sampling sites ($P>0.05$). In May, salinity was an important predictor variable ($P=0.01$), whereas in July, Secchi disk depth was a significant predictor variable ($P=0.03$) for catch of black sea bass. Catch per unit of effort of black sea bass was related to average water depth (coefficient of determination [r^2]=0.21, $P=0.025$) and higher CPUE occurred at deeper (>2 m) sites (Fig. 6).

Seasonal patterns of abundance of black sea bass and temperature

Black sea bass (age 1) began to enter the MCBs from the ocean at an average temperature of 14.21°C in April and 19.34°C in May (Fig. 7, A and B) at sizes ranging from about 45 to 135 mm TL (Fig. 2). Throughout the annual sampling period, size of black sea bass increased and sizes of fish caught ranged from 45 to 224 mm TL in September. Starting in June, smaller size fish (age 0) were captured in the bays (Figs. 2 and 7). The abundance of age-0 fish peaked in September, whereas the abundance for the age-1 year class peaked in July (Fig. 7A) when temperature also peaked at 27.5°C (Fig. 7B). The CPUE of age-1 black sea bass declined from July to October (Fig. 7A) when temperature also began to decrease (Fig. 7B).

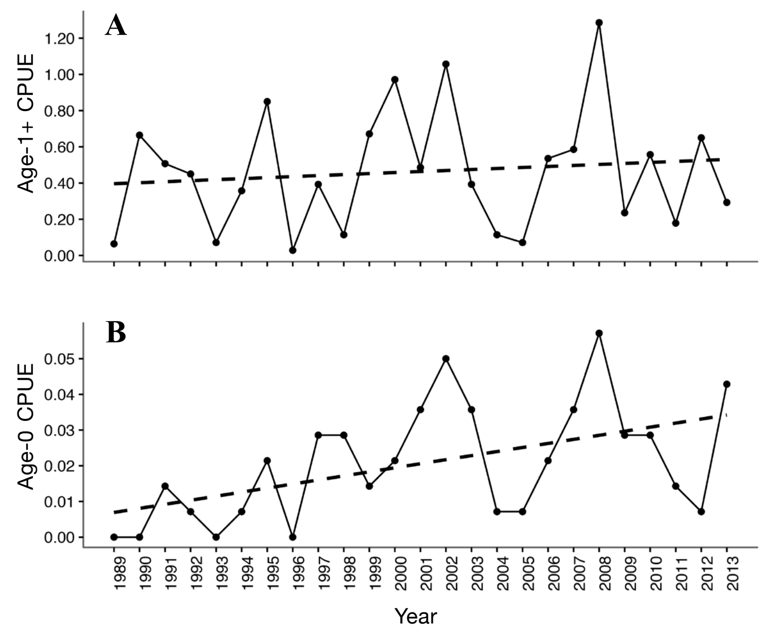

Figure 3

Catch per unit of effort (CPUE) of (**A**) age-1 and (**B**) age-0 black sea bass (*Centropristis striata*) in Maryland coastal bays from trawl surveys conducted during 1989–2013. The dashed line in panel B indicates a significant positive increase ($P<0.05$).

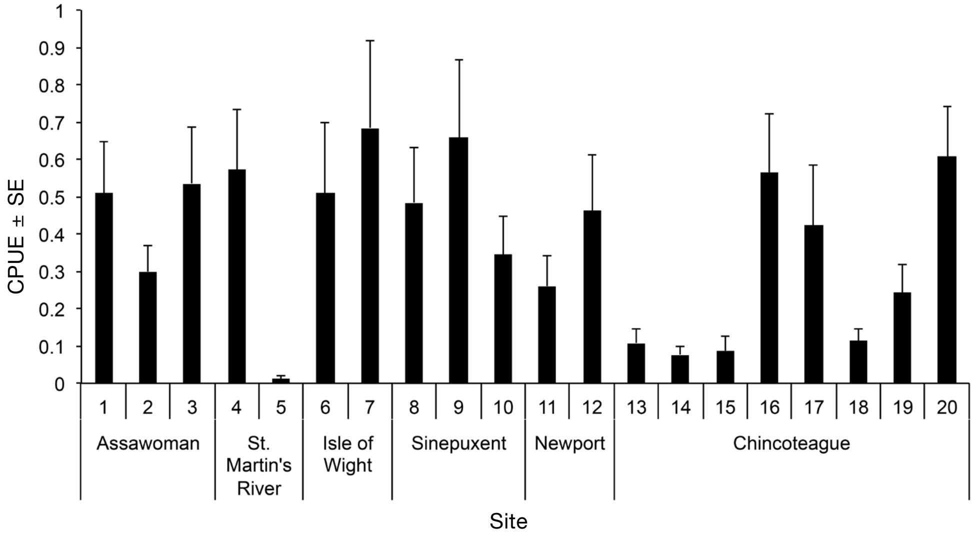

Figure 4

Mean catch per unit of effort (CPUE) for black sea bass (*Centropristis striata*) at various sites in Maryland coastal bays sampled during trawl surveys during 1989–2013. Data were averaged across years. Error bars indicate standard error of the mean.

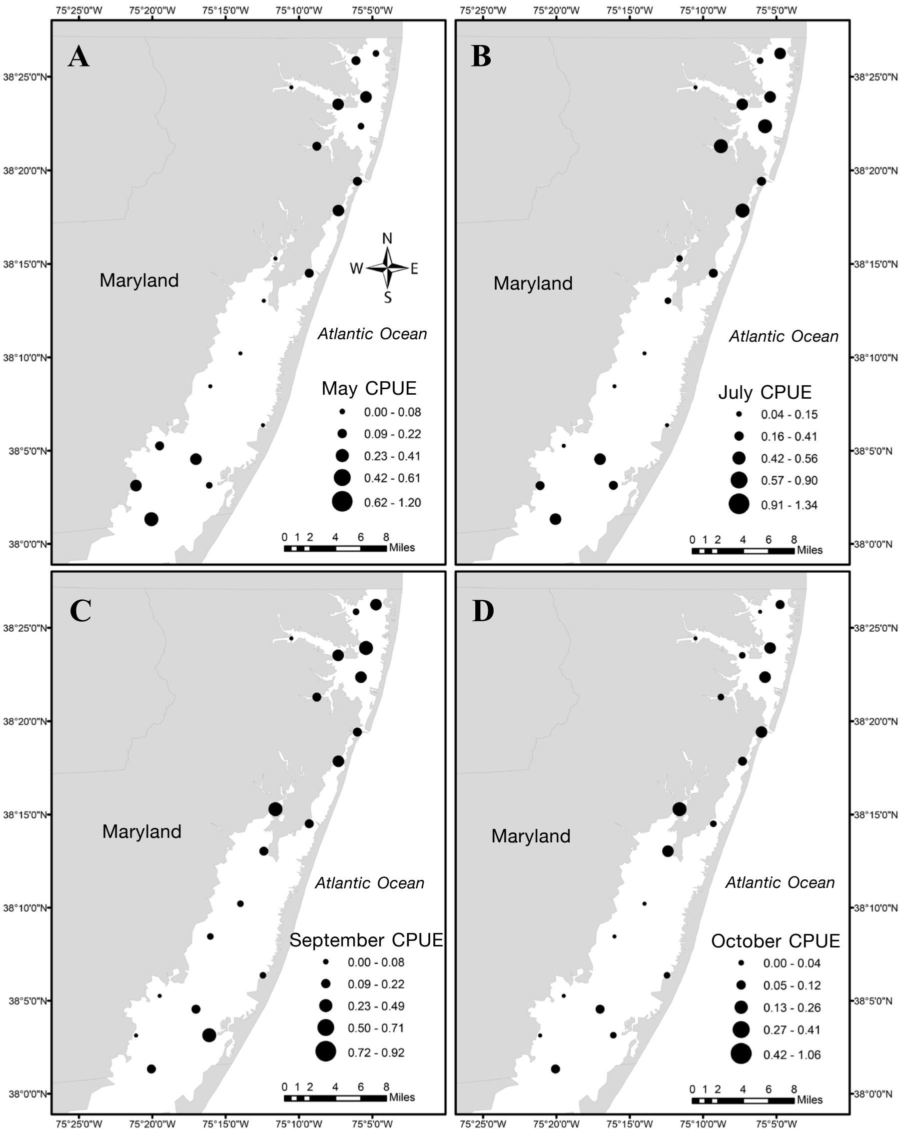

Figure 5

Spatial distribution of black sea bass (*Centropristis striata*) in Maryland coastal bays in (**A**) May, (**B**) July, (**C**) September, and (**D**) October, derived from a time series of catch per unit of effort (CPUE) determined from trawl surveys conducted monthly during 1989–2013.

Results from the GLMs show that average salinity at the sampling sites and the annual NAO index (AIC=90.07) are the most informative predictors of YOY abundance in the MCBs each year, and that salinity is the only significant predictor variable (Tables 1 and 2); the annual NAO index alone was not an informative predictor of age-0 catch (AIC=109.7). Catch of age-0 black sea bass was affected positively by salinity (P=0.0015) and negatively by the annual NAO index (P=0.0468).

Model results showed no trend in the residuals (Fig. 8) and a chi-square goodness-of-fit test showed no significant difference (P=0.166) between the observed and predicted values (Fig. 9). Owing to possible overdispersion, a negative binomial and zero-inflated model were run to compare AIC values from the Poisson model and the negative binomial and zero-inflated model. Comparisons of AIC values indicated that the GLM with a Poisson distribution (AIC=90.07) had the lowest AIC value and fitted the data best when compared with the 2 other models (negative binomial AIC=92.07, zero-inflated AIC=92.26).

Discussion

There was no significant increasing or decreasing trend in abundance of juvenile black sea bass from 1989 to

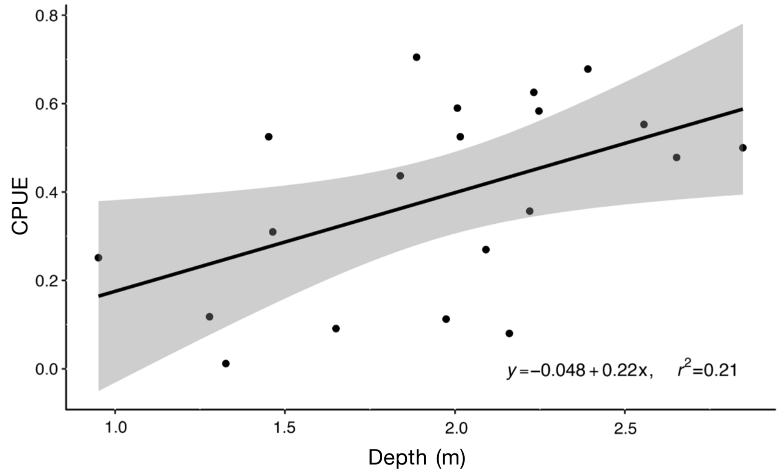

Figure 6

Relationship between catch per unit of effort (CPUE) for juvenile black sea bass (*Centropristis striata*) and average water depth (in meters) ($P=0.025$) from trawl surveys conducted by the Maryland Department of Natural Resources during 1989–2013. r^2=coefficient of determination.

Table 1

Generalized linear model results used to examine the relationship between catch of age-0 black sea bass (*Centropristis striata*) and environmental factors. Average salinity and annual North Atlantic Oscillation (NAO) index (Akaike information criterion [AIC]=90.07) are the best predictors of abundance of young-of-the-year black sea bass. Other factors in the models include temperature, NAO winter, spring, and summer indices, El Niño Southern Oscillation (ENSO), ENSO index, spring (ENSO.MAM) and winter (ENSO.DJF) indices, and spawning stock biomass (SSB). Catch data used were from a time series collected during 1989–2013 in Maryland coastal bays.

Model no.	Model	AIC
1	Age-0 catch ~ Salinity + Temperature + NAO + ENSO + ENSO.MAM + ENSO.DJF + NAO.summer + NAO.winter + NAO.spring+ SSB	100.14
2	Age-0 catch ~ Salinity + Temperature + NAO + ENSO + ENSO.MAM + ENSO.DJF + NAO.winter + NAO.spring + NAO.summer	99.14
3	Age-0 catch ~ Salinity + Temperature + NAO + ENSO + ENSO.MAM + ENSO.DJF + NAO.winter + NAO.spring	97.68
4	Age-0 catch ~ Salinity + Temperature + NAO + ENSO + ENSO.MAM + ENSO.DJF + NAO.winter	95.73
5	Age-0 catch ~ Salinity + Temperature + NAO + ENSO + ENSO.MAM + ENSO.DJF	93.76
6	Age-0 catch ~ Salinity + Temperature + NAO + ENSO + ENSO.MAM	92.75
7	Age-0 catch ~ Salinity + Temperature + NAO + ENSO	93.37
8	Age-0 catch ~ Salinity + Temperature + NAO	91.76
9	Age-0 catch ~ Salinity + Temperature	93.73
10	Age-0 catch ~ Salinity + NAO	90.07
11	Age-0 catch ~ Salinity	91.74

2013; however, some years did show strong year classes. Miller et al. (2016) found that spring during years of 2000, 2002, 2008, and 2012 were strong recruitment years for age-1 black sea bass, which is similar to our results. The catch of age-0 black sea bass did not correlate with abundance of age-1 black sea bass for the following year (t+1), indicating that the catch of age-0 black sea bass cannot predict abundance of age-1 fish of the following year. A similar observation was made by Miller et al. (2016) and was attributed to overwinter mortality that determined the strength of the year class.

Table 2

Results from the generalized linear model with the lowest Akaike information criterion (model 10 in Table 1), indicating that catch of age-0 black sea bass (*Centropristis striata*) in the Maryland coastal bays during 1989–2013 was affected positively by salinity (P=0.00153) and negatively by the annual North Atlantic Oscillation (NAO) index (P=0.04685). Standard errors (SEs) and 95% confidence intervals (CIs) are given for estimates. *z-value*=estimated regression coefficient divided by the standard error of the regression coefficient; the test statistic for the Wald test.

	Estimate	SE	*z*-value	*P*-value	95% CI
Intercept	–5.53401	2.09018	–2.648	0.00811	–9.79–(–1.57)
Salinity	0.23363	0.07374	3.168	0.00153	0.09–0.38
NAO	–0.54019	0.27177	–1.988	0.04685	–1.05–0.01

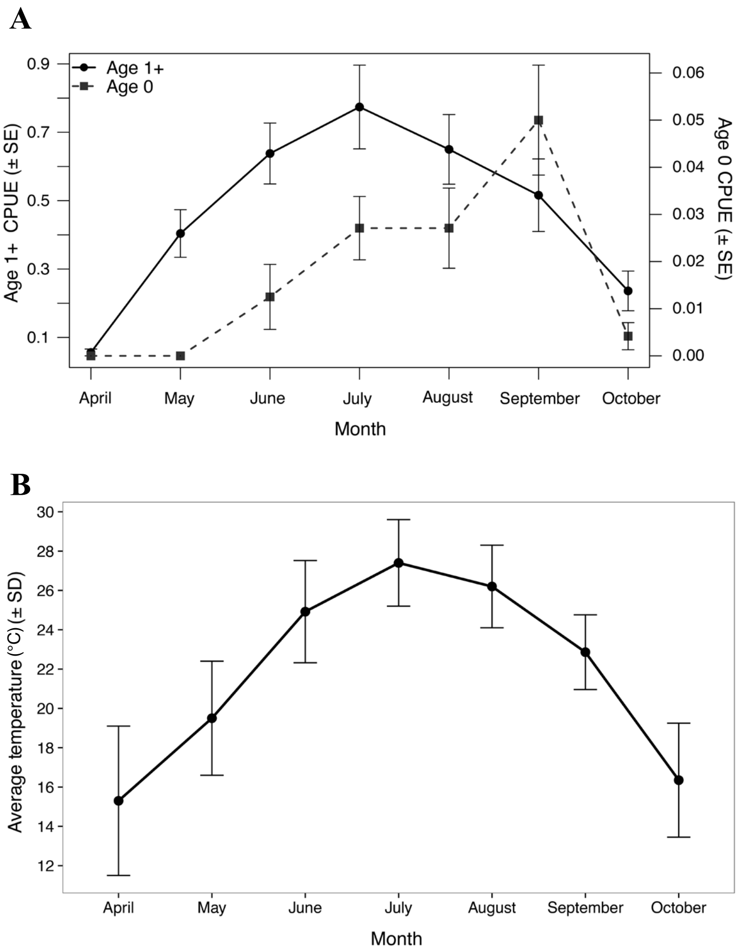

Figure 7

Monthly average (**A**) catch per unit of effort (CPUE) for age-1 and age-0 black sea bass (*Centropristis striata*) and (**B**) temperature from trawl surveys conducted during 1989–2013 in Maryland coastal bays. Data are averages across years. Error bars indicate standard error and standard deviation, respectively.

There was an increasing trend in YOY black sea bass caught in the MCBs from 1989 to 2013, suggesting increasing recruitment of black sea bass to estuarine habitats over time. Juvenile black sea bass were first captured in the bays in April and May and peaked in abundance in July; YOY were caught in the trawls in June and their abundance peaked in September. Adult black sea bass in the Mid-Atlantic Bight spawn from April until November and spawning occurs earlier in southern areas by Virginia (Shepherd and Nieland[3]). Depending on the year, YOY individuals can begin to enter the MCBs as early as June, but their abundance does not peak until September in the MCBs, which is consistent with Musick and Mercer's (1977) results showing that YOY enter estuaries after settling in coastal waters from July to September. In previous studies conducted in New Jersey, YOY were found in estuaries from July through October (Able et al., 1995).

Numbers of black sea bass began to increase in May, suggesting this is the time when they begin to enter the bays in larger numbers. In May they were most abundant in the southernmost part (site 20) of the Chincoteague Bay close to the Chincoteague Inlet. This finding suggests that black sea bass may enter initially through that inlet in May. When waters cool in the fall, black sea bass migrate offshore in a southerly direction to areas across the continental shelf (Musick and Mercer, 1977; Steimle et al., 1999). Once waters begin to warm in April they move inshore, generally along the same route (Kolek, 1990; Moser and Shepherd, 2009), which may be

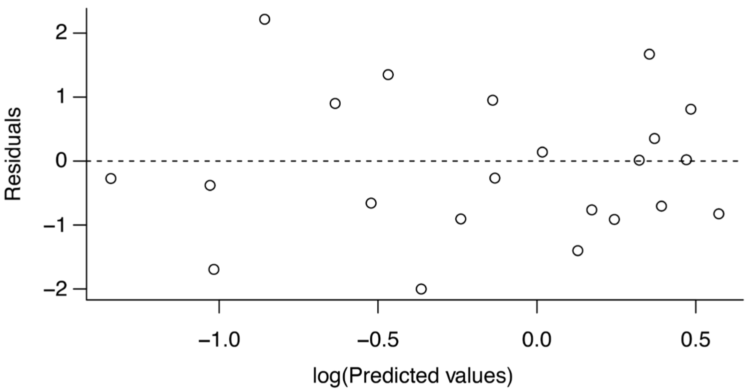

Figure 8

Diagnostic plot for the generalized linear model with the lowest Akaike information criterion (residuals versus log-transformed predicted values). This model was chosen as the best indicator for predicting recruitment of black sea bass (*Centropristis striata*) in the Maryland coastal bays.

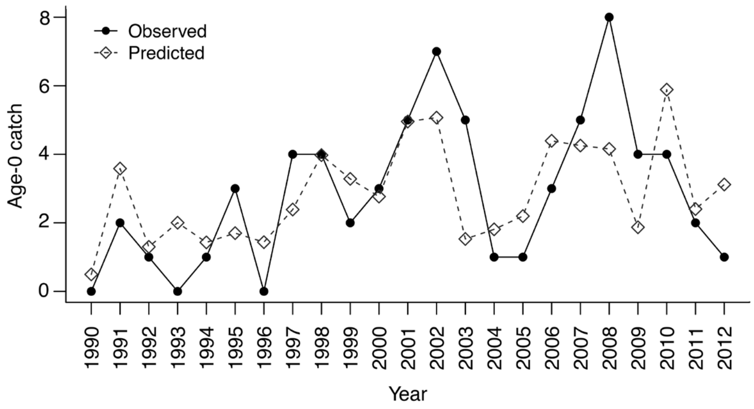

Figure 9

Observed and predicted values of catch of black sea bass (*Centropristis striata*) recorded during Maryland Department of Natural Resources surveys from the generalized linear model with a Poisson distribution and the lowest Akaike information criterion (age-0 catch ~ salinity + annual North Atlantic Oscillation index). A chi-square goodness of fit test (P=0.166) revealed no significant difference between the observed and predicted values.

why the highest abundance of black sea bass occurred in the southernmost site in May in this study.

Catch per unit of effort of black sea bass correlated with water depth, but not with temperature or dissolved oxygen. In the MCBs, there were not much within-season spatial differences in temperature and dissolved oxygen, which perhaps explains why the spatial distribution of juvenile black sea bass was not correlated with the environmental factors. In New Jersey estuaries, black sea bass were found in the deeper area of estuaries (>2 m), not the shallower parts (<1 m) (Able and Hales, 1997). The depth at each site in the MCBs ranged from 0.90 to 2.88 m. Low CPUE occurred at depths of 0.50–1.00 m and high CPUE at sites with depths greater than 2 m. Results from this study and past studies suggest juvenile black sea bass prefer deeper areas of estuaries.

Black sea bass were more abundant in Assawoman, Isle of Wight, and Sinepuxent Bays than in Newport Bay and the central part of Chincoteague Bay. Because abiotic factors measured did not show much correlation with the abundance of black sea bass, other factors, such as proximity to the inlets through which the black sea bass enter and leave the bays and availability of physical structure in the bays, are likely the reasons for differences in abundance between sites sampled in the survey. Able et al. (1995) found that black sea bass were more abundant in habitats with sand and shell bottoms, and in areas where amphipod tubes were abundant. A study that examined the effects of oyster shell planting on fish abundance in the Chincoteague Bay found that catch rates of black sea bass increased when shells were added (Arve, 1960). Because black sea bass are a structure-oriented species, their distribution may be affected by the presence and amount of available structured habitat; however, there is currently little information on the distribution of structured benthic habitats in the MCBs. The only known information on benthic cover is that seagrasses are more abundant on the eastern than the western half of the bays, macroalgae are more abundant in the northern than southern bays (Morales-Núñez and Chigbu, 2016), and oyster shells and beds are scarce. In other estuaries, juvenile black sea bass are rarely seen over nonvegetated sandy areas (Allen et al., 1978), but are commonly seen in areas of high shell density and structured habitats, such as wharves, oyster reefs, and rock reefs (Drohan et al., 2007).

The growth rate of black sea bass from May until September was determined to be 0.58 mm TL/day. There was no significant correlation between growth rate each year and the average temperature and abundance of black sea bass for those years; however, the numbers of fish caught in the trawls were low and this might have been responsible for the lack of significant correlations. Previous studies using a mark–recapture method in a New Jersey estuary found that black sea bass grow rapidly during the summer, with a growth rate of 0.74 mm TL/day from July to September, and with an average of 0.45 mm TL/day from spring through fall (Able and Hales, 1997). A laboratory study found that growth of black sea bass was higher when habitat structure was provided (Gwak, 2003). Because black sea bass are found in areas of hard bottom, the availability of structure may affect the growth rate of the juveniles found in the MCBs. Future studies will have to be conducted to test this hypothesis, but in studies of juvenile North African catfish (*Clarias gariepinus*), an increase in resting time was observed when structure in the habitat was present—increased resting time would lead to an increase in growth rate (Hecht and Appelbaum, 1988).

Understanding climatic effects on recruitment of black sea bass is crucial for the management of the species because the abundance of the fish that contribute to the fishery depends on the number of recruits. In this study, we found that average salinity and the NAO index best predict recruitment of black sea bass. Catch of YOY black sea bass showed a significant positive relationship with salinity, which suggests that their abundance is relatively higher in the MCBs in years of lower-than-average freshwater discharge. In fact, the relatively high CPUE of YOY black sea bass in 1991, 1997 to 2002, and 2006–2008 corresponded with years of higher salinity, whereas the lower CPUE in 1990 and 2004–2005 corresponded with years of lower salinity in the MCBs (P. Chigbu, unpubl. data). Cotton et al. (2003) found that 20 and 30 were optimal salinity levels for YOY black sea bass. YOY black sea bass can tolerate salinities as low as 9 (Berlinsky et al., 2000), but they are primarily found in higher salinity areas of estuaries (Drohan et al., 2007). Because YOY black sea bass prefer areas of higher salinity and structured habitats, largely polyhaline coastal lagoons such as the MCBs may be very important habitats in contrast to river-dominated estuaries that experience larger salinity fluctuations. A recent study found that salinity may be important in the habitat selection of juvenile black sea bass in offshore areas of the continental shelf in the Mid-Atlantic Bight (Miller et al., 2016). During the overwintering period, juvenile black sea bass were found in areas with salinity levels of 33–35; years with strong recruitment in the spring were also years with warmer temperatures, higher salinity levels, and higher shelf water volume (Miller et al., 2016).

In the MCBs, CPUE of age-0 black sea bass was also higher when the NAO index was negative, which is associated with decreased westerly winds and lower temperatures in the region. The colder air during years with negative NAO indices brings less precipitation to the eastern United States and results in less freshwater discharge and higher salinity in estuaries and the coastal ocean (Cullen et al., 2002) that, perhaps, favor recruitment of black sea bass.

This study provides the first information on the spatial and temporal fluctuations in abundance of juvenile black sea bass in the MCBs. The results of our study provide insight into how a changing environment may impact recruitment of black sea bass into estuaries and show that future studies assessing the effects of climate change on recruitment of YOY black sea bass are important for the future conservation of the estuarine habitats that black sea bass inhabit and for the fishery that targets this species. Information from this study can form a basis for more studies of black sea bass in mid-Atlantic coastal lagoons in order to increase our understanding of the importance of these features as nursery habitats for the species.

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