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Multi-decadal variation in size of juvenile Summer Flounder (*Paralichthys dentatus*) in Chesapeake Bay

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ABSTRACT

During the last quarter-century, management of Summer Flounder *Paralichthys dentatus* along the Atlantic coast resulted in significant increases in abundance such that rebuilding targets were recently achieved. Although spawning stock biomass is high, recruitment of young-of-the-year (YOY) Summer Flounder remains variable. Chesapeake Bay is one of the principal nursery areas for this species, but processes such as growth and survival that affect production of YOY Summer Flounder in this estuary have not been explored. Here, we investigated the relationship between abundance and size of Summer Flounder recruits from the 1988 to 2012 year classes in Chesapeake Bay. We also considered the effects of environmental factors on fish size because conditions in the bay vary spatially during the time that fish occupy nursery areas. To describe variations in Summer Flounder size, we used monthly length observations from 13,018 YOY fish captured by bottom trawl from the lower Chesapeake Bay and the James, York, and Rappahannock river subestuaries where Summer Flounder are commonly observed. We applied a generalized additive model to describe spatial, temporal, and environmental effects on observed fish size; we also considered the density of Summer Flounder and an index of productivity as factors in the model. Summer Flounder in Chesapeake Bay exhibited density-dependent and spatially related variations in mean length: larger fish were found mostly in the Bay and smaller fish in the subestuaries. Additionally, low (<13 °C) and high (>26 °C) temperatures and low salinities (<10 psu) had a negative effect on fish size, indicating that individuals found in these environments were typically smaller than conspecifics inhabiting areas of moderate temperatures and higher salinities. Variable nursery habitat conditions in temperate estuaries affect fish size and, subsequently, may influence production of Summer Flounder year classes through effects on maturation and survival. As water temperatures in the mid-Atlantic region continue to increase, YOY Summer Flounder size may be negatively affected.

1. Introduction

Juvenile fishes inhabiting temperate estuaries are subjected to large fluctuations in temperature, salinity, and dissolved oxygen on daily and seasonal scales (Able and Fahay, 2010); these fluctuating conditions may lead to variability in size of individual fish and their subsequent survival (Gibson, 1994; Houde, 2008). Growth rates of fishes are typically highest during their first year of life, when fast growth is believed to be critical for survival because rapid growth allows fish to attain sizes that permit escapement from predators (e.g., Campana, 1996; Islam et al., 2010; Joh et al., 2013; Tupper and Boutilier, 1995). Fish growth and the size structure of the cohort may also be influenced by cohort abundance, such that smaller fish are observed when density of conspecifics is high (Lorenzen and Enberg, 2002). Indeed, density-dependent size variations have been documented for juvenile estuarine fishes including American Shad *Alosa sapidissima* (Tuckey, 2009), Striped Bass *Morone saxatilis* (Martino and Houde, 2012), Spot *Leiostomus xanthurus* (Craig et al., 2007), and European Plaice *Pleuronectes platessa* (Ciotti et al., 2014; Geffen et al., 2011; Pihl et al., 2000). In habitats where size-selective predation is an important component of juvenile mortality, larger individuals are more likely to survive than smaller ones (Miller et al., 1988; Sogard, 1997; Witting and Able, 1993) and larger individuals may therefore make a greater contribution to year–class strength (Houde, 2008).

Many factors influence growth and subsequent size of juvenile fish. For example, in flatfishes variable growth rates of juveniles have been associated with variations in environmental conditions among nursery habitats, in particular, temperature and dissolved oxygen concentrations (Winter Flounder *Pseudopleuronectes americanus*: Phelan et al., 2000; Sogard et al., 2001; Southern Flounder *Paralichthys lethostigma*: Fitzhugh et al., 1996). In some species, variable growth results from variations in the onset of piscivory and prey availability (Southern Flounder, Fitzhugh et al., 1996). In the mid-Atlantic region, Summer Flounder *Paralichthys dentatus* is an important flatfish supporting commercial and recreational fisheries, yet little is known about factors affecting size of Summer Flounder during the first year of life. Because effective management of Summer Flounder requires a better

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understanding of year–class strength, and because size may affect survival, an assessment of size variation in juvenile Summer Flounder from mid-Atlantic estuaries is warranted.

Estuaries from Massachusetts to North Carolina serve as nursery habitat for YOY Summer Flounder (Able and Kaiser, 1994), and the Chesapeake Bay region is a principal nursery area for this species (Norcross and Wyanski, 1994). During the last quarter-century, management of Summer Flounder along the Atlantic coast resulted in significant increases in abundance such that rebuilding targets were recently achieved. Recruitment of YOY Summer Flounder in Chesapeake Bay is variable among years (Tuckey and Fabrizio, 2013a), and shows little relationship to adult spawning stock biomass (Terceiro, 2011). Within a year class, individual YOY Summer Flounder may exhibit large variations in length (L. Nys, pers. obs.), which likely reflects multiple cohorts that comprise the year class. These cohorts arise because adult Summer Flounder spawn in continental shelf waters of the mid-Atlantic Bight during an extended period of time, typically from September to February (Morse, 1981; Smith, 1973). Protracted spawning results in multiple cohorts of eggs and larvae entering Chesapeake Bay from December to April (Ribeiro et al., 2015). Compared with other estuarine fishes, YOY Summer Flounder exhibit relatively fast growth (1.3 mm/day, Rountree and Able, 1992) and individuals may exceed 290 mm total length (TL) by the end of their first year of life (Szedlmayer et al., 1992; Tuckey and Fabrizio, 2013a). As a result of the fast growth of YOY fish, a portion of the population may reach maturity at age-0. In Summer Flounder, at least 50% of males > 240–270 mm and 50% of females > 300–330 mm are mature (Morse, 1981). Some age-0 fish attain these sizes by late summer or early fall; thus, fast-growing YOY fish are more likely to be mature and contribute to stock production. The most recent stock assessment considered that 38% of age-0 Summer Flounder was mature (NEFSC, 2013), but this proportion is likely to vary annually due to size variations among individuals within the age-0 cohort.

In this study, we investigated factors that contribute to variation in size of YOY Summer Flounder in Chesapeake Bay, Virginia, including environmental conditions and density of conspecifics. We also explored implications of individual fish size variation to production of the stock. Our study is unique because we consider 25 years of monthly size data (individual lengths) for Summer Flounder together with environmental conditions at the time of collection. Observations of the size of wild fish from temporally intense samples can yield insights on the relationship between fish size and the environmental conditions from which fish were collected. In many flatfishes, growth increments are formed on the otolith with constant frequency, allowing for determination of length-at-age (Nash and Geffen, 2005). However, this approach is not viable for YOY Summer Flounder because otolith increment formation is not daily during the pelagic larval stage (Szedlmayer and Able, 1992). Furthermore, otoliths of YOY Summer Flounder do not exhibit checks that permit identification of key life-history events such as hatching or settlement; therefore, calculation of hatch date, settlement date, and daily age is not possible (pers. obs.). By examining changes in total length of fish collected from Chesapeake Bay nurseries, we sought to gain insight on factors potentially influencing fish size.

Based on reports for other flatfishes, we postulated that size is variable among age-0 Summer Flounder, and that this variation is related to physical and environmental conditions, prey availability, and density of conspecifics. In particular, we expected water temperature (Malloy and Targett, 1994), dissolved oxygen concentration (Stierhoff et al., 2006, 2009), and prey abundance (Malloy and Targett, 1994) to affect the size of wild-captured Summer Flounder. In laboratory experiments, juvenile Summer Flounder grew faster (and as such, could attain larger sizes) at 14–18 °C than did conspecifics exposed to colder temperatures (2–10 °C); however, salinities between 10 and 30 psu had no effect on growth or size of juveniles (Malloy and Targett, 1991). A reduction in the growth rate of juvenile Summer Flounder occurs when fish are exposed to dissolved oxygen levels between 3.5 and 5 mg O_2/l, with further reductions in growth in hypoxic (<2.0 mg O_2/l) conditions (Stierhoff et al., 2006). Negative effects of low oxygen conditions on juvenile Summer Flounder growth have also been observed in the wild (Stierhoff et al., 2009), so we would expect to observe reduced fish size in habitats with low dissolved oxygen concentrations. Finally, growth is highly dependent on the feeding rate of juvenile Summer Flounder (Malloy and Targett, 1994); therefore, prey abundance is likely an important determinant of fish size. Although laboratory experiments can be useful to elucidate factors affecting growth and variation in fish size, field studies provide a more realistic assessment of changes in size under the wide variety of conditions experienced by wild fish.

2. Materials and methods

2.1. Fish sampling

Juvenile Summer Flounder representing the 1988 to 2012 year classes were sampled from June to November by the Virginia Institute of Marine Science (VIMS) Juvenile Fish Trawl Survey (hereafter, 'trawl survey'). The trawl survey operates in Virginia's estuarine waters, and uses a 9.14 m semi-balloon otter trawl with 38.1 mm stretched mesh and 6.35 mm cod-end liner towed for 5 min along the bottom (Tuckey and Fabrizio, 2013a). The survey employs a random stratified sampling design based on 4 depth strata (1.2–3.7 m, 3.7–9.1 m, 9.1–12.8 m, and ≥12.8 m) and 18 regions in the lower Chesapeake Bay and in the major tidal tributaries of Virginia. For this study, we measured size (mm total length) of fish collected from the Virginia portion of Chesapeake Bay and from the James, York and Rappahannock river subestuaries. Seventy-eight stations were sampled monthly (11 stations in the lower portion of each subestuary and 45 stations in the bay; Fig. 1). Young-of-the-year Summer Flounder were identified using monthly length thresholds developed from historical monthly length–frequency histograms (Tuckey and Fabrizio, 2013a). For example, a Summer Flounder that measured less than 225 mm captured in August is considered a YOY fish. Our samples were restricted to catches between June and November because this is the time when YOY fish used inshore nursery areas and were fully available to our gear. Before June, YOY Summer Flounder are not frequently encountered in bottom trawl catches, possibly due to their small size or distribution in shallow areas (<1.2 m) that are not sampled by the trawl survey. Summer Flounder emigrate from Virginia estuaries in late fall, and by late November, most fish have typically moved out of Chesapeake Bay (Capossela et al., 2013; Henderson et al., 2014). Therefore, encounter rates with our trawl decline markedly in December.

Density of each year class was estimated using a stratified mean index of abundance (Cochran, 1977). Because the stratification of the trawl survey was designed to ensure broad spatial coverage, and because sample size (number of tows) per stratum in any given month was low (typically 3–6 tows), we calculated relative density of juvenile Summer Flounder as the stratified mean index of abundance using three strata in the Bay (upper, lower, bottom), and two strata (lower, bottom) in each subestuary. At the stratum level, we used a delta-lognormal model to estimate mean stratum abundance. The delta-lognormal model has been used to estimate abundance from research survey catches because such data typically follow a lognormal distribution and also include a high proportion of zeros (Maunder and Punt, 2004; Pennington, 1983, 1996). With this approach, zero catches and non-zero catches are modeled separately, and abundance estimates are calculated using the log-transformed product of the mean and the proportion of non-zero catches (Aitchison, 1955; Lo et al., 1992). Abundance calculations were implemented in SAS® (SAS Institute, Cary, NC). The stratified mean index of abundance serves as a measure of Summer Flounder density under the assumption that the area swept by the trawl is constant; this is a reasonable assumption because tow duration and vessel speed were held relatively constant during the survey and the same gear and protocols were implemented annually. Catches of