



Spatial and temporal variability in growth of southern flounder (*Paralichthys lethostigma*)



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ABSTRACT

Delineation of stock structure is important for understanding the ecology and management of many fish populations, particularly those with wide-ranging distributions and high levels of harvest. Southern flounder (*Paralichthys lethostigma*) is a popular commercial and recreational species along the southeast Atlantic coast and Gulf of Mexico, USA. Recent studies have provided genetic and otolith morphology evidence that the Gulf of Mexico and Atlantic Ocean stocks differ. Using age and growth data from four states (Texas, Alabama, South Carolina, and North Carolina) we expanded upon the traditional von Bertalanffy model in order to compare growth rates of putative geographic stocks of southern flounder. We improved the model fitting process by adding a hierarchical Bayesian framework to allow each parameter to vary spatially or temporally as a random effect, as well as log transforming the three model parameters (L_{∞} , K , and t_0). Multiple comparisons of parameters showed that growth rates varied (even within states) for females, but less for males. Growth rates were also consistent through time, when long-term data were available. Since within-basin populations are thought to be genetically well-mixed, our results suggest that consistent small-scale environmental conditions (i.e., within estuaries) likely drive growth rates and should be considered when developing broader scale management plans.

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1. Introduction

Accurate descriptions of populations and subpopulations are important across all of ecology, but particularly important for commercial fish stocks that experience high amounts of harvest mortality. Methods and descriptions of what make fish stocks unique is an active area of fisheries science owing largely to the fact that ecological groupings can be measured and described in many ways—e.g., spatially, genetically, and phenotypically among others (Cadrin et al., 2013). Although the best stock identification approach involves multiple methods in an interdisciplinary analysis (Begg and Waldman, 1999; Abaunza et al., 2013), such studies are not always feasible. One good starting point, however, is the use of life history traits to begin describing (putative)

populations. Many fishery monitoring programs routinely collect life history data such as age, size, sex, and maturity. These traits often vary across a species range in association with genetic and/or environmental factors, and this variation has important stock assessment and management implications (McBride, 2013).

Life history traits used in stock identification can take a number of forms, but often describe biological processes such as growth, maturation, and fecundity (Pawson and Jennings, 1996; Begg et al., 1999; McBride, 2013). Because these processes occur throughout a population, meaningful comparisons of process rates (or other descriptive parameters) can detect differences that have both ecological and management importance. Numerous studies have investigated life history traits in order to advance the understanding of a specific population of fish. For example, DeVries and Grimes (1997) examined growth of king mackerel (*Scomberomorus cavalla*) over large spatial and temporal ranges to support multiple stocks, and Begg and Marteinsdottir (2002) use sex-specific

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maturity data to evaluate length and age-at-maturity of Atlantic Cod (*Gadus morhua*) over many years.

Although questions of appropriate model use and fit are warranted (Katsanevakis and Maravelias, 2008), many life history relationships are well established. Unfortunately, however, rigorous comparisons of life history parameters are less available, partly due to a lack of well-established methodology. Visual comparison of growth curves to other models certainly has value; however, uncertainty around parameter estimates is often not reported, and in some cases multiple comparisons are subject to questionable post-hoc adjustments (Ruxton and Beauchamp, 2008; Gelman et al., 2012). Few studies have explored hierarchical applications of growth modeling, but Pilling et al. (2002) used a random effects model on back-calculated growth estimates for *Lethrums mahsena* focusing on parameter correlation. Closer to the multiple comparisons focus, Helser and Lai (2004) used a random effects meta-analysis approach on *Micropterus salmoides*. However, Helser and Lai (2004) used mean lengths-at-age and not individual fish data. Building upon both of these studies, we present an alternative parameter comparison technique that is robust to the Type I error issues inherent to many traditional analyses.

Southern flounder (*Paralichthys lethostigma*) are a recreational and commercial flatfish, primarily distributed in nearshore and estuarine habitats in the Atlantic Ocean from southern Virginia to central Florida, and in the Gulf of Mexico from central Florida to northern Mexico (Gilbert, 1986). Range-wide declines in populations have been independently detected and generally attributed to high long-term fishing mortality (in the Atlantic Ocean [Takade-Heumacher and Batsavage, 2009] and Gulf of Mexico [Froeschke et al., 2011]). Currently, no coast-wide assessment (or stock assessment outside of North Carolina) takes place, which limits spatially-extensive inference that can be made on this species.

Males and females exhibit size dimorphism, with females attaining larger sizes (Wenner et al., 1990), and as a result comprising the majority of the fishery by numbers and weight (Takade-Heumacher and Batsavage, 2009). Growth has been estimated independently in locations (Table 1), although the years and data sources vary considerably and thus prevent a robust comparison. Additionally, little is known about sexual differentiation and sex ratios; however, Luckenbach et al. (2003) suggest that sexual differentiation takes place around 100–120 mm total length (TL), and report sex ratios at midrange temperatures near 1:1, but with higher proportions of males at both high and low temperatures. Between ages 1 and 3 years, southern flounder females mature and then move offshore to spawn (Midway and Scharf, 2012), while patterns of male maturation are undocumented.

Based largely on the wide species distribution (and vicariant separation around southern Florida), unknown offshore habitat use during and after spawning, and the recreational and commercial value of the species, stock structure has recently become an area of interest. Genetic work has established two distinct basin populations—the Gulf of Mexico and southeastern US Atlantic Ocean (Anderson et al., 2012). However, genetic work and otolith morphometrics (Midway et al., 2014) have failed to identify any structuring within basins. Despite lack of genetic structuring within basins, phenotypic differences may exist. Previous growth estimation (Table 1) suggests spatial (or temporal) variation, highlighting the possibilities that (1) these variable parameter estimates are accurate and thus serve as a hypothesis for further examination of stock-specific growth, or (2), these variable parameter estimates are inaccurate, and highlight the need for a more unified, comparable way to evaluate model parameters.

Given the genetic difference between Gulf of Mexico and Atlantic Ocean populations, and the fact that growth can be heritable, we hypothesized that growth would differ between basins,

a spatial level at which other stock delineators have found evidence. Mortality (both fishing mortality, F , and natural mortality, M) can impact growth, although in the study areas and over the time we have data, F has likely remained high (Froeschke et al., 2011 in Texas and Takade-Heumacher and Batsavage, 2009 in North Carolina) and M unknown for all stocks; thus, we hypothesize that over time, growth rates have remained relatively stable for southern flounder and any differences in growth reflect environmental or spatial factors. Also, sex ratio data on southern flounder is generally lacking, yet basic biological questions remain about sex differentiation and sex-specific life histories—particularly the disconnect between estimated juvenile sex ratios and the high percentage (80–90%) of females landed in the fishery. We hypothesize that sex ratios at size are consistent across the species range. Thus, the objectives for our work is to both evaluate a new von Bertalanffy parameterization in a Bayesian context, while addressing life history questions for southern flounder.

2. Materials and methods

2.1. Data sources

We used data from fishery-independent sampling programs in North Carolina, South Carolina, Alabama, and Texas in order to evaluate estuarine-specific (spatial), long-term (temporal), and sex-specific differences in southern flounder growth. All four states maintain ongoing fishery-independent sampling programs, and southern flounder data were available for a variety of sampling gears. However, in order to reduce the effect of gear we used only fish collected from fishery-independent inshore gillnet and trammel net sampling. Specifically, we used data from the North Carolina Division of Marine Fisheries (NCDMF) Fisheries Independent Assessment program, which fishes multi-panel gill nets (7.6–16.5-cm stretch mesh in eight 27.4-m sections) in the estuarine waters throughout the state during February–December (see Takade-Heumacher and Batsavage, 2009 for additional programmatic details). South Carolina Department of Natural Resources (SCDNR) data are from their year-round, long-term estuarine trammel net survey that samples with a 183-m long and 2.1-m deep trammel net made up of two 35.56 cm stretch-mesh outer panels and one 6.35 cm stretched-mesh inner panel (Arnott et al., 2010). Gulf of Mexico samples came from the Alabama Department of Conservation and Natural Resources who sample flounder with multi-panel gill nets (6.35–15.24-cm stretch mesh in four 45.7-m sections; John Mareska Personal Communication), as well as the Texas Parks and Wildlife Department estuarine gillnet survey, which uses 7.6–15.2-cm stretch mesh in four 45.7-m sections that are fished for 10-week periods once in the spring and once in the fall (Martinez-Andrade and Fisher, 2012). Sample sizes varied per state as well as differ in the years collected (i.e., in some locations not all sampled fish are aged every year; see Tables 2 and 3 for data summary).

At the time of capture all fish were measured (total length [TL]) and sexed by visual examination of gonads. Otoliths were also extracted, and all ages were estimated by agency biologists using at least one of the sagittal otoliths. North Carolina estimates southern flounder ages using two reads of whole otoliths submerged in water with sectioning as needed. Alabama and Texas biologists sectioned southern flounder otoliths prior to reading (VanderKoooy and Guindon-Tisdell, 2003). South Carolina southern flounder otoliths were aged using whole otoliths until 2004, and sectioned otoliths have been used since, although it has been shown (with South Carolina-caught southern flounder) that whole otolith and sectioned otolith ages overwhelmingly agree (Wenner and Roumillat, unpublished data). In general, southern flounder

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