# EFFECTS OF HURRICANES ON ATLANTIC CROAKER (*MICROPOGONIAS UNDULATUS*) RECRUITMENT TO CHESAPEAKE BAY

M.M. Montane and H.M. Austin

Department of Fisheries Science, Virginia Institute of Marine Science
College of William & Mary, Gloucester Point, VA 23062

## ABSTRACT

Few studies have focused on the effects of climatic perturbations, such as hurricanes, on finfish recruitment and behavior. The Virginia Institute of Marine Science (VIMS) Trawl Survey has sampled continuously throughout the Virginia portion of Chesapeake Bay for 50 years. While hurricanes have impacted Chesapeake Bay during this time, three periods of hurricane activity—September and November 1985 (hurricanes Gloria and Juan), September 1989 (Hurricane Hugo), and September 2003 (Hurricane Isabel)—coincided with the largest spikes in juvenile recruitment of Atlantic croaker (*Micropogonias undulatus*) for half a century. The fall (October–December) croaker young-of-year indices for 1985, 1989, and 2003 were seven, five, and eight times greater, respectively, than the 50-year average. Typically Atlantic croaker display great interannual variability in Chesapeake Bay, with these fluctuations shown to be weather related. The timing of Atlantic croaker recruitment to Chesapeake Bay is such that late summer/fall hurricanes are most likely to affect them, as opposed to other shelf spawners. Understanding the effects of hurricanes on species, such as croaker, that have enormous ecological, commercial, and recreational importance is essential for prudent fisheries management.

## INTRODUCTION

The Chesapeake Bay and its tributaries form the largest estuary in the continental United States, providing food and shelter to more than 260 fish species [1] and countless crustaceans and other invertebrates. Estuarine organisms, such as molluscs, crustaceans, and fishes, support important commercial and recreational fisheries [2]. Their temporal distributions and recruitment are often dependent on annual climatic conditions and water currents [2]. Additionally, species not supporting fisheries are ecologically important, serving as key predators or prey items within the Bay [3]. The recent occurrence of a forceful hurricane (Hurricane Isabel) in the Bay, as well as the prediction of high levels of hurricane activity in this region for the next 10–40 years [4], warrant an investigation into whether recruitment of important marine species might be impacted. The objective of this study was to examine the effects of hurricanes on Atlantic croaker recruitment to Chesapeake Bay.

Three types of spawning activity occur in the Chesapeake Bay [5]: spring anadromous spawning (striped bass - *Morone saxatalis* and Alosidae), summer Bay spawning (bay anchovy - *Anchoa mitchelli*; blue crab - *Callinectes sapidus;* weakfish - *Cynoscion regalis*; and American oyster - *Crassostrea virginica*) and fall-winter shelf spawning (Atlantic menhaden - *Brevoortia tyrannus*; spot - *Leiostomus xanthurus*; Atlantic croaker; and summer flounder - *Paralichthys dentatus*). The majority of northwest Atlantic hurricanes occur in the late summer/fall and, therefore, are most likely to affect the fall/winter shelf spawners, particularly those that recruit heavily to Chesapeake Bay for only a few short months during this time (e.g., Atlantic croaker).

Atlantic croaker is one of the most abundant inshore demersal fishes along the southeastern coast of the United States [1, 6]. Croaker first spawn at

*K.G. Sellner (ed.). 2005. Hurricane Isabel in Perspective. Chesapeake Research Consortium, CRC Publication 05-160, Edgewater, MD.*

age 2–3 from July through December in estuarine [7] and continental shelf waters between Delaware Bay and Cape Hatteras [8], with peak spawning August through October off Chesapeake Bay [1, 9]. Pelagic young of year (YOY) of 8–20 mm total length (TL) leave shelf waters and enter larger estuaries, eventually moving into nursery habitats associated with low-salinity tidal creeks [8]. The YOY (20 mm TL) first enter the Chesapeake Bay in August and move into freshwater creeks and low-salinity nursery habitat [1]. Croaker larvae generally enter the Bay in the deeper inward flowing water with greatest concentrations below 3 m [10]. Initial fall recruit-ment of croaker depends on fall continental shelf winds to provide transport into the Bay, with shelf winds and winter temperature explaining 89% of the variance in subsequent summer year-class strength [11]. If wind relaxation occurs prior to the autumn migration of croaker out of the estuaries, spawning occurs in the middle portion of the Mid-Atlantic Bight [12]. Prolonged summer winds keep nearshore waters cool and force the croaker further south to spawn, potentially shifting distribution of juvenile recruitment to southern Pamlico Sound [12]. In autumn, the young croaker move into the deeper portions of tidal rivers, where they overwinter and leave the Bay as adults the following fall [1].

Interannual variability in croaker abundance may be climate related, with colder winters causing increased mortality in overwintering YOY [6, 13]. During cold winters, the spawning population may be pushed farther south along the coast, reducing the number of postlarval fish capable of reaching nursery areas of the Bay [1, 14]. When average January–February water temperatures remain above 4.0º C, juvenile croaker recruited into the Bay survive in greater numbers [11]. Cold tolerance in juvenile croaker is size and salinity dependent; smaller individuals survive longer than larger ones and their cold tolerance increases with increasing salinity [13].

Recruitment of fall/winter shelf spawners may be impacted by hurricanes, but appears to be initially dependent on the timing of the seasonal wind shift in the Mid-Atlantic Bight (and its resultant effect on bottom-water temperatures), including variations in strength, duration, and direction of wind-driven transport [11]. For example, a late wind shift would result in croaker spawning south of Cape Hatteras [12] and introduction of a hurricane may have negligible effects on recruitment to Chesapeake Bay as the croaker larvae have already been displaced. Conversely, an early seasonal wind shift may enhance croaker recruitment to the Bay. Thus a hurricane occurring in mid- to late August may preempt the usual shift to northeast winds which occurs in early September and accelerate the warming of nearshore waters, thereby stimulating the croaker to spawn weeks earlier close to Chesapeake Bay.

## MATERIALS AND METHODS

The annual presence (or absence) of hurricanes in Virginia was determined through examination of the NOAA National Weather Service Hydrometeorological Prediction Center website detailing late 20th-century hurricanes in Virginia [15]. Wind at Norfolk International Airport [16] was deemed to be a proxy for offshore winds (Godshall as reported by [11]) and plotted with MATLAB [17]. Both daily and weekly resultant direction and speed were examined. A two-week moving average was applied to weekly data to filter out storm effects and ascertain when the late summer/early fall offshore wind shift or cessation of summer winds may have occurred (see [12] for details). Wind stress was examined through calculation of monthly meridional wind values.

The VIMS Juvenile Finfish and Blue Crab Trawl Survey (1955 to present) was used for this study because of its long duration and spatial coverage, which includes major Virginia tributaries (James, York, and Rappahannock rivers) and the lower portion of Chesapeake Bay [18]. A lined 30-ft (9.14 m) semi-balloon otter trawl, 1.5-in (38.1 mm) stretched mesh, and 0.25-in (6.35 mm) cod liner was towed along the bottom for 5 minutes during daylight hours. Water quality was measured at each station with a YSI 650 hydrographic meter. Both Bay and major tributaries were sampled with a random stratified design. Stratification was based on depth and latitudinal regions in the Bay (random stations only), or depth and longitudinal regions in the rivers (random and fixed stations; see [18] for further sampling details). The survey random stratified converted index (RSCI) incorporated gear and vessel changes [19] to provide an uninterrupted time series for five decades [18]. Individual species indices were derived based on modal analyses and aging studies as well as monthly catch rates [20].

The Fall Atlantic Croaker YOY Index (fall YOY) is composed of the following months and respective individual fish total lengths (TL): October (0–80 mm); November (0–100 mm); and December (0–100 mm). The following Spring Atlantic Croaker Recruit Index (spring recruit) is composed of the following months and respective TL: May (0–135 mm); June (0–160 mm); July (0–180 mm); and August (0–220 mm). Numbers of individuals caught were log transformed (ln (n+1)) prior to abundance calculations. Resultant average catch rates (and the 95% confidence intervals as estimated by $\pm$ 2 standard errors) were then back-transformed to the geometric means.

A one-way analysis of variance was performed with fall YOY as the response variable and annual presence of hurricanes (non-hurricane vs. hurricane years in Virginia) as the factor for the years 1956–2004. A multiple regression was performed with fall YOY as the response variable and time of cessation of summer winds and monthly meridional wind stress (July through December) as the predictor variables. A linear regression was performed with the spring recruits ($yr^{-1}$) as the response variable and the fall YOY as the predictor variable for the same time period.

## RESULTS AND DISCUSSION

Hurricane Isabel struck Chesapeake Bay from 18–19 September 2003 and produced prolonged onshore winds and sustained wind stress up-estuary for many days prior [21]. Beginning 5 September, there were 8 consecutive days of strong NE winds, 2 days of S and SE winds, and 5 additional consecutive days of NE winds. The cessation of summer winds and resultant wind shift occurred during late August 2002, middle September 2003, and late September 2004—roughly two weeks later each year. Post-storm mean surface salinities at fixed stations in the James, York, and Rappahannock rivers dropped 3.5, 3.2, and 3.0 psu while bottom salinities decreased 3.6, 0.5, and 2.2 psu, respectively. Only stations furthest upriver (nearly freshwater) were unaffected.

The 2003 fall YOY index was 15 times greater than the 2002 index, eight times the survey average, and the highest for the duration of the survey for almost half a decade (Figure 1). Major peaks in 1985, 1989, and 2003, coincided with hurricanes Gloria and Juan (27 September and 2–7 November, 1985), Hugo (21–22 September 1989), and Isabel (18–19 September), resulting in indices seven, five, and eight times greater than the 50-year average (mean = 13.0, s.e. = 3.1).

Minor peaks were evident during 1969 (Camille), 1996 (Fran), and 1998 (Bonnie). One year not associated with hurricanes with a high fall YOY index (1984) may have resulted from prolonged winds associated with normal hurricane activity. Meridional wind stress during August and September 1984 was fairly strong. The fall YOY index was significantly greater (by a factor of three) during hurricane years than non-hurricane years

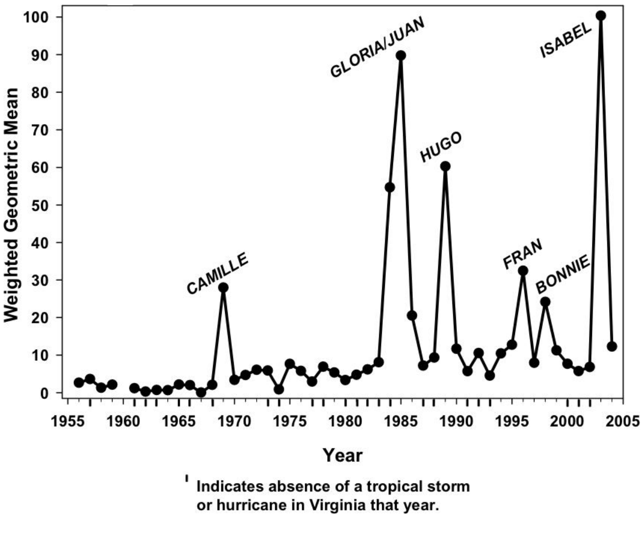


**Figure 1.** VIMS fall young-of-year croaker index.

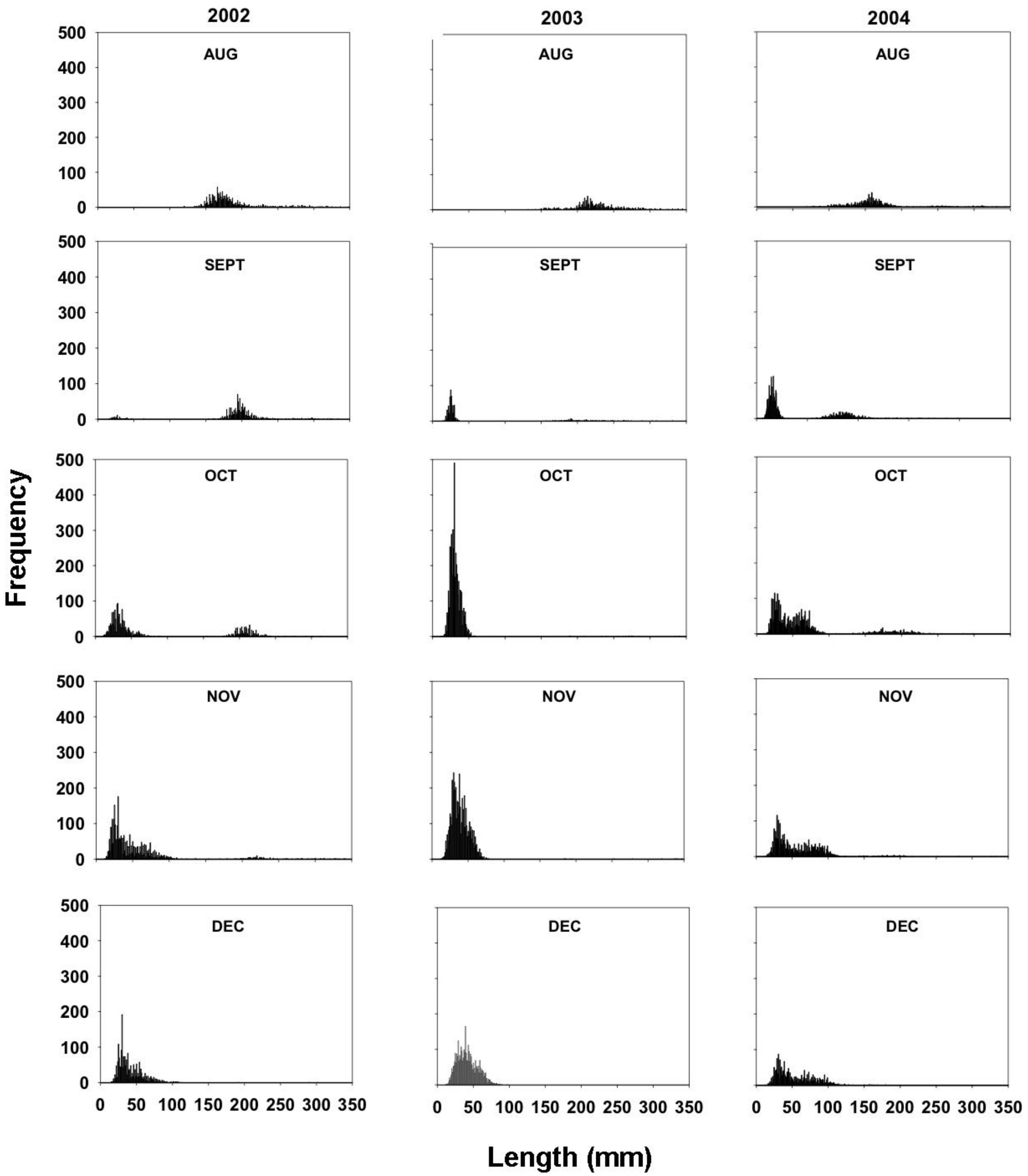


**Figure 2.** Atlantic croaker size frequencies for August through December 2002 (left), 2003 (center), and 2004 (right).

($F_{0.05, 1, 46}$; P = 0.041). Only August meridional wind stress was a significant predictor of the fall YOY index (P= 0.044). When cessation of summer winds occurred during September, the fall YOY index was highest. This situation was true for both 1985 and 2003.

A comparison of monthly size frequencies from August through December 2002, 2003, and

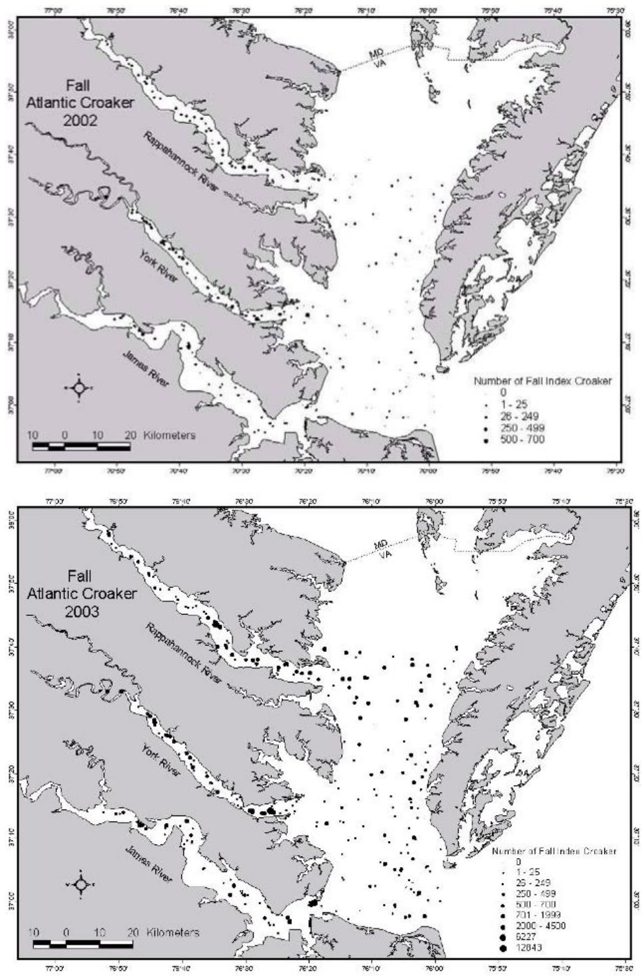


**Figure 3.** Abundance and distribution of Atlantic croaker during fall 2002 (top) and fall 2003 (bottom).

2004 reveals the enormous increase of YOY croaker less than 50 mm TL present in October 2003 compared to the same months in 2002 and 2004 (Figure 2). Note also that 150–225 mm TL croaker were conspicuously absent during September and October 2003. There was also a notable difference between the abundance and distribution of croaker collected during fall 2002 and fall 2003 (Figure 3, top and bottom). Densities of YOY croaker were elevated in the main stem and lower portions of rivers during fall 2003 (Figure 3, bottom) compared to the previous year (Figure 3, top)—probably due to a combination of downriver displacement of the croaker resulting from decreased salinities and wind-driven transport of YOY into the Bay. The mean YOY croaker catch per station was an order of magnitude higher in fall 2003 compared to fall 2002 (means of 448.5, s.e.= 53.2; and 45.0, s.e.=5.41, respectively).

The very successful year classes in the fall of 1984, 1985, 1989, and 2003 often did not result in comparably successful recruitment the following spring (Figure 4). There was no significant linear relationship between the fall YOY and following spring recruit indices (P=0.62).

Significant weather events, such as tropical storms may impact fish and crustacean populations in Chesapeake Bay directly by changing the salinity of the water, preventing or enhancing larval entrance into the Bay due to wind events or indirectly by causing habitat declines (see Houde et al., this volume). Drastic changes in environmental variables (i.e., changes in salinity, dissolved oxygen) may directly affect the mortality rates of pre-recruits or indirectly exert influence by altering the abundance of forage predators [21]. Some species, such as newly settled juvenile blue crabs, may actually benefit from storms as the increased turbidity may favor chemotactic (blue crab) search modes, but have negative impacts on visual predators (e.g., Atlantic croaker and other finfish) [22].

The spike in the 2003 fall YOY croaker index was related to persistent onshore winds associated with Isabel. The next highest fall YOY index occurred in 1985, coincident with Gloria (27 September) and Juan (2-7 November), followed by Hugo (September 1989). Winds in 2003 shifted from southwest to northeast about two weeks later than 2002, suggesting that croaker spawned later in 2003 and larval croaker may have been displaced farther south. However, strong northeast winds from Isabel and the resultant Ekman transport enhanced transfer of croaker larvae back into the Bay, resulting in the spike of croaker less than 50 mm TL in October 2003. Due to the shape and orientation of the Bay coastline, larval transport models have shown that larvae can only recruit back to the Bay from the south under a wind stress with a large north-northwesterly component [23]. Larval transport to the Bay can be enhanced through large-scale advection from wind-forced inflow events that bring large volumes of water into the Chesapeake as described above. Hurricane Juan moved 8 $km^3$

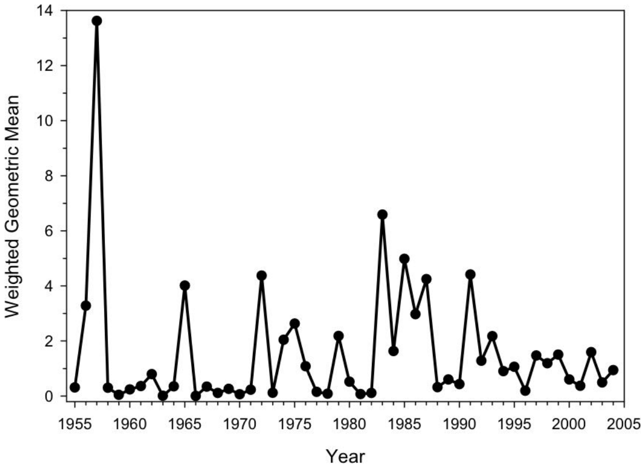


**Figure 4.** VIMS spring recruit Atlantic croaker index.

of shelf water into the Bay resulting in a large blue crab megalopal settlement event during early November 1985 [24]. Incidentally, nearly a three-fold increase occurred in the VIMS Trawl Survey fall (September through November) blue crab YOY index in 2003, compared to 2002. An increase is not always the result, however, as hurricanes in North Carolina during 1996 and 1999 resulted in blue crab recruitment failure with significant declines in YOY and postlarval abundance [25].

Storms and hurricanes may be beneficial to species. For example, menhaden may have evolved to reproduce under physical conditions (similar to hurricanes) optimal for the survival and shoreward transport of its eggs and larvae [26]. These physical conditions include storms (during which upwelling and spawning occur) and persistent heat loss and stratification (during which rapid development and shoreward transport occur). In addition, species such as spot, croaker, flounder, striped mullet (*Mugil cephalus*), and pinfish (*Lagodon rhomboides*) spawn south of Cape Hatteras and west of Gulf Stream fronts, using estuaries as nursery habitats [11, 26, 27, 28, 29]. All of these species have evolved to spawn during winter, shoreward of a warm boundary current, allowing rapid development and drift of their eggs and larvae and ultimately resulting in enhanced recruitment and fitness [26]. In Chesapeake Bay, hurricanes do not appear to enhance recruitment of spot and flounder, as indicated by our trawl indices for these species.

Large variations in annual fisheries landings in Chesapeake Bay are common and most often attributed to natural phenomena [30]. Interannual variability in croaker and blue crab abundance may be climate related, with colder winters causing increased mortality in overwintering YOY in Chesapeake Bay [6, 31] and along the Mid-Atlantic Bight [13]. During these same winters, the spawning population may be pushed farther south along the coast, reducing the number of postlarval fish capable of reaching nursery areas of the Bay [1, 14]. When average January–February water temperatures are above 4.0º C, juvenile croaker recruited into the Bay survive in greater numbers [11]. Additionally, striped bass are known to prey heavily on overwintering YOY croaker in Chesapeake Bay (Dovel, 1968 as reported in [7]). Even though hurricanes may aid recruitment of species such as Atlantic croaker to Chesapeake Bay, cold winters and predation (as discussed above) may result in only average abundances of the recruits the following spring and summer [18].

Recent climate conditions (winter/spring patterns) affecting Chesapeake Bay (rather than hurricanes) appear to have reduced annual recruitment in species such as spot and Atlantic menhaden [29]. However, the effect of hurricanes (which are predicted to be more frequent in the future) on recruitment of important ecological, commercial, and recreational species should be taken into consideration by fisheries managers, as different species may be impacted in various ways by different storms.

## ACKNOWLEDGMENTS

The authors would like to thank Wendy Lowery for help with data analysis and graphics and the numerous Trawl Survey staff for the past half century. Funding sources over the duration of the study have included U.S. Fish and Wildlife Wallop-Breaux, Commonwealth of Virginia, Virginia Marine Resources Commission, and presently the NOAA Chesapeake Bay Office. This paper is Virginia Institute of Marine Science Contribution No. 2650.

## REFERENCES


1. E.O. Murdy, R.S. Birdsong, and J.A. Musick. 1997. *Fishes of Chesapeake Bay*. Smithsonian Institution Press. 324 pp.
2. S.L. Stone, T.A. Lowery, J.D. Field, C.D. Williams, D.M. Nelson, S.H. Jury, M.E. Monaco, and L. Andreasen. 1994. Distribution and abundance of fishes and invertebrates in Mid-Atlantic estuaries. ELMR Rep. No. 12. NOAA/NOS Strategic Environmental Assessments Div., Silver Spring, MD. 280 pp.
3. R.J. Wood, E.D. Houde, and S. Jung. 2003. Variability in the dynamics of forage fish abundances in Chesapeake Bay: Retrospective analysis, models and synthesis. Chesapeake Bay Fisheries Research Program Symp. Report, NOAA-CBO. pp. 97–107.
4. S.B. Goldenberg, C.W. Landsea, A.M. Mestas-Nunez, and W.M. Gray. 2001. The recent increase in Atlantic Hurricane activity: causes and implications. *Science* 293: 474–479.
5. H.M. Austin. 2002. Decadal oscillations and regime shifts, a characterization of the Chesapeake Bay marine climate. *Amer. Fish. Soc. Symp.* 32: 155–170.
6. E.B. Joseph. 1972. The status of the sciaenid stocks of the Middle Atlantic Coast. *Chesap. Sci*. 13(2): 87–100.
7. L.R. Barbieri, M.E. Chittenden, Jr., and S.K. Lowerre-Barbieri. 1994. Maturity, spawning, and ovarian cycle of Atlantic croaker, *Micropogonias undulatus*, in the Chesapeake Bay and adjacent coastal waters. *Fish. Bull.* 92: 671–685.
8. K.W. Able and M.P. Fahay. 1998. *The First Year in the Life of Estuarine Fishes in the Middle Atlantic Bight*. Rutgers University Press, New Jersey. 342 pp.
9. W.W. Morse. 1980. Maturity, spawning and fecundity of Atlantic croaker, *Micropogonias undulatus*, occurring north of Cape Hatteras, North Carolina. *Fish. Bull.* 78: 190–195.
10. B.L. Norcross. 1991. Estuarine recruitment mechanisms of larval Atlantic croakers. *Trans. Amer. Fish. Soc.* 120: 673–683.
11. B.L. Norcross. 1983. Climate scale environmental factors affecting year-class fluctuations of Atlantic croaker (*Micropogonias undulatus*) in the Chesapeake Bay. Ph.D. Dissertation. College of William & Mary. 388 pp.
12. B.L. Norcross and H.M. Austin. 1988. Middle Atlantic Bight meridional wind component effect on bottom water temperatures and spawning distribution of Atlantic croaker. *Cont. Shelf Res.* 8: 69–88.
13. T.E. Lankford, Jr. and T.E. Targett. 2001. Low-temperature tolerance of Age-0 Atlantic croakers: Recruitment implications for U. S. Mid-Atlantic Estuaries. *Trans. Amer. Fish. Soc.* 130: 236–249.
14. E.D. Houde. 2002. The unique contributions of early life stages. In: *Fishery Science*. L.A. Fuiman and R.G. Werner (eds.). Blackwell Publishing, pp. 64–87.
15. NOAA National Weather Service. *2004*. Virginia Hurricane History: late Twentieth Century. *www.hpc.ncep. noaa.gov/research/roth/valate20hur.htm*
16. NOAA National Weather Service. 2004. *www.erh.noaa.gov/er/akq/climate/climate.htm*
17. MATLAB. 2004. Version 7.0. The MathWorks, Inc.
18. M.M. Montane, W.A. Lowery, and H.M. Austin. 2004. Estimating relative juvenile abundance of ecologically important finfish and invertebrates in the Virginia portion of Chesapeake Bay. Annual Report to NOAA-CBO, Project No. NA03NMF4570378. VIMS, Gloucester Pt., VA. 106 pp.
19. D.N. Hata. 1997. Comparisons of gears and vessels used in the VIMS juvenile finfish trawl survey. SRAMSOE No. 343. VIMS, Gloucester Pt. VA. 244 pp.
20. J.A. Colvocoresses and P.J. Geer. 1991. Estimation of relative juvenile abundance of recreationally important finfish in the Virginia portion of Chesapeake Bay. Annual Report to VMRC/USFWS Sportfish Restor-ation Project F104R1. July 1990 to June 1991. VIMS, Gloucester Pt. VA. 64 pp.

22. R.E. Ulanowicz, M.L. Ali, A. Vivian, D.R. Heinle, W.A. Richkus, and J.K. Summers. 1982. Identifying climatic factors influencing commercial fish and shellfish landings in Maryland. *Fish. Bull.* 80(3): 611–619.
23. A.J. Pile, R.N. Lipcius, J. van Montfrans, and R.J. Orth. 1996. Density-dependent settler-recruit-juvenile relationships in blue crabs. *Ecol. Monogr.* 66(3): 277–300.
24. J.A. Quinlan, B.O. Blanton, T.J. Miller, and F.E. Werner. 1999. From spawning grounds to the estuary: Using linked individual-based and hydrodynamic models to interpret patterns and processes in the oceanic phase of Atlantic menhaden *Brevoortia tyrannus* life history. *Fish. Oceanogr.* 8 (Suppl. 2): 224–246.
25. D.M. Goodrich, J. van Montfrans, and R.J. Orth. 1989. Blue crab megalopal influx to Chesapeake Bay: Evidence for a wind-driven mechanism. *Est. Coast. Shelf Sci.* 29: 247–260.
26. J. Burkholder, D. Eggleston, H. Glasgow, C. Brownie, R. Reed, G. Janowitz, M. Posey, G. Melia, C. Kinder, R. Corbett, D. Toms, T. Alphin, N. Deamer, and J. Springer. 2004. Comparative impacts of two major hurricane seasons on the Neuse River and western Pamlico Sound ecosystems. *Proc. Nat. Acad. Sci.* 101(25): 9291–9296.
27. D.M. Checkley, Jr., S. Raman, G.L. Maillet, and K.M. Mason. 1988. Winter storm effects on the spawning and larval drift of a pelagic fish. *Nature* 335: 346–348.
28. D. Bodolus. 1994. Mechanisms of larval spot transport and recruitment to the Chesapeake Bay. Ph.D. Dissertation. College of William & Mary. 350 pp.
29. M.P. Weinstein. 1981. Plankton productivity and the distribution of fishes on the southeastern U. S. Continental Shelf. *Science* 214: 351–352.
30. R.J. Wood. 2000. Synoptic scale climatic forcing of multispecies recruitment patterns in Chesapeake Bay. Ph.D. Dissertation. College of William and Mary. 146 pp.
31. Rothschild, B.J. 1984. Trends in Chesapeake Bay Fisheries. *Trans. 46th N. Amer. Wildl. Nat. Res. Conf.* 46: 284–298.
32. A.F. Sharov, J.H. Volstad, G.R. Davis, B.K. Davis, R.N. Lipcius, and M.M. Montane. 2003. Abundance and exploitation rate of the blue crab (*Callinectes sapidus*) in Chesapeake Bay. *Bull. Mar. Sci.* 72(2): 543–565.