

**Blue Crab Habitat and Management in Chesapeake Bay**

by

Judith Gayle Pugh

A major paper submitted to the faculty of Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Natural Resources

David L. Trauger, Chairman  
W. Reid Goforth  
Alexandra R. Isern  
Jonathan T. Phinney

April 21, 2005

Alexandria, Virginia

Key words: *Callinectes sapidus*, ecosystem-based management, marine protected area, hypoxia

# **Blue Crab Habitat and Management in Chesapeake Bay**

by Judith Gayle Pugh

## **Abstract**

Blue crabs are currently the most economically important species harvested from Chesapeake Bay and the fishery has declined since the early 1990's. Recovery and sustainability of the valuable blue crab fishery hinges on protection of nursery habitat, foraging grounds and spawning grounds. The fishery supports hundreds of watermen in Virginia and Maryland, both commercially and recreationally. Commercial landings since the early 1990's have been decreasing even though more time and effort has been expended in harvesting. Research indicates that fishing mortality and decline in spawning stock biomass are preventing blue crabs from rebounding. The decrease in spawning stock has perpetuated the risk of recruitment failure. While blue crab population sizes are naturally variable, declines are usually followed by recovery. Since an abrupt decrease in 1992, the blue crab population in Chesapeake Bay has not shown signs of recovery, although the population has shown signs of stabilization over the past three years. Blue crabs are found throughout Chesapeake Bay in different habitats at different life stages, stressing the need for Baywide ecosystem management to ensure recovery. A significant amount of research is being conducted to enhance the stock, understand habitat preferences, natural mortality, predator-prey interactions and harvesting impacts. Many questions remain regarding the life cycle of the blue crab, including the actual life span. Therefore, it is important that different life stages receive some form of protection to improve blue crab abundance.

## **Acknowledgements**

I recognize the following individuals for guidance in the preparation of this paper: David L. Trauger of Virginia Polytechnic Institute and State University; W. Reid Goforth of the U.S. Fish and Wildlife Service (Retired); Alexandra R. Isern and David G. Garrison of the National Science Foundation; Jonathan T. Phinney of the National Oceanic and Atmospheric Administration (on rotation from University of Maryland); and Romuald N. Lipcius and Rochelle D. Seitz of Virginia Institute of Marine Science.

## Table of Contents

Abstract.....	ii
Acknowledgements.....	iii
Table of Contents.....	iv
Figure .....	v
I. Introduction .....	1
II. Blue Crab Decline in Chesapeake Bay .....	3
III. Coordinated Recovery Efforts .....	4
IV. Ecology of the Blue Crab .....	6
V. Blue Crab Fisheries in Chesapeake Bay .....	8
VI. Habitat.....	9
Recruitment and habitat .....	9
Juvenile and male habitat.....	10
Female and annual migration.....	11
VII. Habitat Disturbance.....	12
VIII. Marine Protected Areas.....	15
IX. Blue Crab MPA in Chesapeake Bay.....	17
X. Ecosystem Fisheries Management.....	19
XI. Conclusions.....	21
References.....	22
Vita .....	28

**Figure**

Fig. 1. Baywide SAV Cover from 1986-2001 .....13

## I. INTRODUCTION

The blue crab, *Callinectes sapidus*, has significant economic, ecological and social importance throughout the Chesapeake Bay region and is the most economically valuable species harvested from Chesapeake Bay (National Oceanic and Atmospheric Administration 2004, Miller and Houde 1998). The dockside value for 31.3 kilograms of blue crabs was \$73 million in 1997 (Miller and Houde 1998). Blue crabs are also important ecologically especially in the predator-prey dynamics of the estuary. Finally, blue crabs are integrated into the life styles of many people living in close proximity to Chesapeake Bay, whether in recreational fishing or dining at a crab house.

In spite of the importance of blue crabs, the population has declined substantially throughout Chesapeake Bay. An abrupt decrease occurred from 1991-1992, severely impacting the population and it has not recovered to meet harvesting demands. As a result, harvests from 1999-2003 were approximately 30% below the annual average from 1968 to 2002 (Chesapeake Bay Commission 2003).

Reasons the blue crab population is declining are multiple, but the most accepted reasons are related to poor quality of habitat and over exploitation of different life stages. Vital foraging and nursery grounds are being removed or degraded, inhibiting growth and development of remaining blue crabs. A significant decrease in spawning stock abundance has exacerbated the decline (Lipcius and Stockhausen 2002). In response, state managers in Virginia enlarged the spawning sanctuary located in lower Chesapeake Bay twice in the last five years. The spawning sanctuary is in effect only during peak spawning season and late migrating females and overwintering females are not protected. Recovery and sustainability of the valuable blue crab fishery hinges on the protection of nursery habitat, foraging grounds and spawning grounds. The

purpose of this paper is to evaluate the habitat resources and management of those resources that are important to the blue crab life cycle.

## **II. BLUE CRAB DECLINE IN CHESAPEAKE BAY**

Annual variation in abundance is normal for blue crabs, and an abrupt decrease in population size may result from an environmental disturbance such as a hurricane or severely cold winter. Studies in Delaware Bay suggest a blue crab population will recover from a sharp decline within 7 to 8 years (Helser and Khan 2001). The population in Chesapeake Bay, however, has not followed this pattern. An abrupt decrease in abundance in 1992 was followed by a moderate increase in 1993, but since then the population has continued to decline. Despite the decrease, fishing pressure has remained high (Chesapeake Bay Commission 2003). From the 1940s to 2001, harvests varied by an order of 2 magnitudes, but since then harvests have been the lowest since World War II (Thomas Miller, Benthic Ecology Conference, April 8, 2005) and more crab pots are being used to catch fewer crabs. The Potomac River Fisheries exemplify this trend with fishing approximately 210 pots and harvesting more than 100 bushels each year from 1986 to 1991, but approximately 250 pots were fished and less than 75 bushels harvested in 2001 and 2002 (Chesapeake Bay Commission 2003).

Research results indicate that a decrease in spawning stock biomass and low recruitment have prevented blue crabs from recovering (Lipcius and Stockhausen 2002). Spawning stock abundance has declined by 81% and female size decreased 8% from 1992-2000 (Lipcius and Stockhausen 2002). A decrease in spawning stock size reduces larval abundance and recruitment. Several factors including heavy fishing, environmental degradation (i.e., decreased water quality, salinity fluctuations, hypoxia) and destruction of nursery habitats have contributed to this problem.

### **III. COORDINATED RECOVERY EFFORTS**

Significant effort is being coordinated within state and federal agencies with jurisdiction over Chesapeake Bay to reverse the decline in blue crab abundance. Research has focused on important habitat, predator-prey interactions and ecosystem dynamics that affect blue crabs.

In 1997, the National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) directed the first Baywide stock assessment of the blue crab population through the Chesapeake Bay Stock Assessment Committee (CBSAC). The CBSAC prepares annual Blue Crab Advisory Reports detailing blue crab harvests and abundance to guide management decisions. The initial assessment resulted in the Blue Crab Fishery Management Plan (FMP). The blue crab FMP was the first to address the effects of water quality and submerged aquatic vegetation (SAV) on fishery yields (Orth et al. 2002).

In 1983, the Chesapeake Bay Program (CBP) was established to address degraded environmental conditions by signing the Chesapeake Bay Agreement. The CBP coordinates restoration efforts for Maryland, Virginia, Pennsylvania, District of Columbia and federal agencies with common goals to reduce anthropogenic eutrophication and protect the resources in Chesapeake Bay. The U.S. Environmental Protection Agency (EPA) coordinates federal involvement in CBP activities. The Chesapeake Bay Commission (CBC) is the legislative branch of CBP that advises Maryland, Virginia and Pennsylvania on matters concerning Chesapeake Bay. The CBC established the Bi-State Blue Crab Advisory Committee (BBCAC) as a technical advisory group to analyze and advise on management of blue crabs for the Maryland, Virginia and Potomac River Fisheries. The BBCAC was active from 1996 to 2003 and involved scientists, legislators, watermen and other stakeholders. Due to lack of funding the BBCAC was disbanded in 2003.

Research efforts for blue crab recovery have started to transition from single species to ecosystem-based management because multiple species of economical and ecological important have shown population declines in Chesapeake Bay in recent decades. The goal of ecosystem-based fisheries management is to improve multiple fisheries that are interconnected. Habitat requirements and ecological contributions of blue crabs encompass the Chesapeake Bay ecosystem making the blue crab a model species to demonstrate the importance of an ecosystem approach to management.

#### **IV. ECOLOGY OF THE BLUE CRAB**

The blue crab is an ecologically important species in the Chesapeake Bay serving as both predator and prey and for the transfer of carbon in benthic and planktonic systems (Seitz et al. 2001). Postlarvae and early juveniles are prey for by eel, drum, spot, croaker, striped bass, sea trout, catfish and larger blue crabs. Adult blue crabs are omnivorous although clams make up the majority of their diet (Seitz et al. 2001).

The blue crab has a complex life cycle and is partitioned by habitat relative to age and gender (Etherington and Eggleston 2000). The life of a blue crab begins at the mouth of the estuary. Female blue crabs spawn in the high salinity water in lower Chesapeake Bay from late spring to early fall on nocturnal ebb and morning tides (Carr et al. 2004). The larvae (zoea), are transported by currents, and advect towards the continental shelf outside the estuary. Larvae presumably develop offshore to prevent osmotic-stress in the low salinity water of the estuary (Carr et al. 2004). After undergoing 6 or 7 molts in 30-45 days, the zoea have developed into postlarvae (megalopae) and have swimming capabilities.

Megalopae are transported into Chesapeake Bay by a combination of wind-generated currents and flood tides where they migrate vertically in the water column in response to light and tide (Epifanio and Garvine 2001). In Chesapeake Bay, submerged aquatic vegetation (SAV) provides settlement habitat for recruits where megalopae molt into the first juvenile or instar phase. (Instar refers to the increase in size of an organism caused by periodic shedding of the exoskeleton (Pile et al. 1996).) During the instar phase, the blue crab develops its characteristic appearance and increases in carapace width with the first post larvae molt. As the blue crab continues to undergo ecdysis (molting), increasing in size, it moves out of the SAV and into the

tributaries and upper reaches of Chesapeake Bay. Blue crabs reach maturity around 12 to 18 months.

Mating occurs from May to October, upon which females will mate only once and this occurs at the time of her final or “terminal” molt. Eggs are released 2 to 9 months after mating when an egg mass develops on the underside of the abdomen. Females may release 3 to 8 million eggs per spawning event (Burreson et al. 2000, Hines et al. 2003). If left unharvested, female crabs will spawn several times from the single insemination (Burreson et al. 2000, Hines et al. 2003). Neither the spawning life cycle of a female is known nor how many times she actually spawns in Chesapeake Bay. In fact, the life span of the blue crab is not known because the age of the blue crab cannot be identified past the second year (Hewitt and Hoenig 2005).

## **V. BLUE CRAB FISHERIES IN CHESAPEAKE BAY**

A variety of strategies are used to harvest crabs that targeting different stages of the life cycle. Types of harvesting methods include: (1) crab pot (hard shell), (2) peeler pot (soft shell) (3) winter dredge, (4) peeler pound and traps (5) scrape, and (6) trot line (Seitz et al. 2001).

The pot fishery accounts for 86.5% of the landings in Virginia and is composed of approximately 70% females (Burreson et al. 2000). In Maryland the pot fishery accounts for 61-67% of the fishery (Burreson et al. 2000) and is slightly less than 50% female composition. The winter dredge fishery takes place in Virginia and accounts for approximately 13.5% of Virginia harvests. Trotlines are used in Maryland where pots are prohibited (Seitz et al. 2001) and accounts 30-36% of Maryland harvests (Burreson et al. 2000). The total harvests from peeler pounds and scrape methods account for 1-2% of the total harvests throughout Chesapeake Bay (Burreson et al. 2000). The recreational fishery accounts for approximately 15% of the annual Baywide harvests of blue crabs (Seitz et al. 2001).

In Maryland and Virginia, the pot fishery targets hard shell crabs that are 127 mm or greater in carapace width and the pots have cull rings that allow small crabs to escape. Peeler pots are used to attract females ready for terminal molt and a male crab is placed in the upper portion of the pot attracting females ready to mate.

## **VI. HABITAT**

Blue crab nursery habitats, foraging grounds and spawning grounds have all been degraded, fragmented or heavily targeted for harvesting. Thereby potentially reducing crab genetic diversity, abundance and distribution (Stockhausen and Lipcius 2003).

A clear understanding of the spectrum of habitats that are significant to the life cycle of the blue crab is necessary to identify spatial and temporal protective measures that need to be identified to keep the fishery at sustainable levels. For example, high salinity water at the mouth of Chesapeake Bay is required for spawning and early life stages. Whereas juveniles and adult males migrate to lower saline water in tributaries, tidal creeks and salt marshes where benthic fauna is abundant.

### **Recruitment and habitat**

SAV provides initial habitat for megalopae and eelgrass, *Zoestra marina*, is the preferred SAV (Pile et al. 1996, Stockhausen and Lipcius 2003). Physical processes along with vertical swimming capability, and response to light chemical cues, all allow megalopae to locate optimal settlement habitat and avoid predation (Forward et al. 2003).

The increased need for refuge for growing crabs along with decreased refuge protection results in a habitat shift for juvenile blue crabs (Moksnes et al. 1997). *Z. marina* distribution is temporal in Chesapeake Bay with peak biomass in early summer (May-June) (Hovel and Lipcius 2002). Blue crab cannibalism occurs in *Z. marina* after peak settlement events when blue crab densities exceed 15 crabs/m<sup>2</sup> (Moksnes et al. 1997). Therefore, cannibalism significantly influences both mortality and settlement rates for recruits (Moksnes et al. 1997). In order to

escape cannibalism, juvenile crabs disperse to alternate habitats in the estuary by the fifth juvenile instar (Orth and van Montfrans 2002, Pile et al. 1996).

### **Juvenile and male habitat**

Unvegetated sand and mud habitats adjacent to salt marshes and tidal creeks provide nursery habitat, foraging grounds and overwintering locations (Seitz et al. 2003). These areas and the “turbidity maximum”, where water masses of different salinities mix, are vital nursery and foraging habitats because they contain high densities of clams, which constitute the majority of the blue crab’s diet (Seitz et al. 2001, Seitz et al. 2003, Dittel et al. 1995). Shallow water in all of these areas hinders predation and high turbidity provides additional protection from sediment that inhibits predator vision (Dittel et al. 1995). By the ninth instar stage, juveniles are most abundant in unvegetated habitats because they have reached a size where they are less susceptible to predation or “size refuge” of 18-20 mm (Orth and van Montfrans 2002, Pile et al. 1996).

Adult blue crabs need protection from predation when they undergo ecdysis. Inter-molt blue crabs are the main predator upon molting blue crabs (Ryer et al. 1997). A significant majority of males approaching ecdysis migrate from river basins to tidal creeks and a few migrate to SAV (Hines et al. 1987, Ryer et al. 1997). Molting blue crabs spatially aggregate from non-molting crabs to alleviate the risk of cannibalism through the dilution effect (Ryer et al. 1997).

## **Female and annual migration**

Female blue crabs are more abundant in deeper water and lower Chesapeake Bay than male crabs (Burreson et al. 2000). Pubertal females approaching ecdysis are found in river basins where mature inter-molt males are abundant (Ryer et al. 1997). When the female undergoes her terminal molt, she is inseminated and protected by the male until her exoskeleton is hard. After the terminal molt and mating, female blue crabs allocate energy to rebuilding muscle mass to prepare for migration to mouth of the estuary (Turner et al. 2003). The female migrates to higher salinity water at the mouth of the estuary during nocturnal ebb tides and remains at or near the bottom during flood tides (Carr et al. 2004). Females are referred to as a sponge when the developed egg mass extrudes from the abdomen (Burreson et al. 2000). Female crabs mating in upper Chesapeake Bay have a great distance to travel and may not reach the spawning grounds until October where they overwinter at the mouth of the estuary or in route to the spawning grounds, and spawn in the spring (Turner et al. 2003).

## **VII. HABITAT DISTURBANCE**

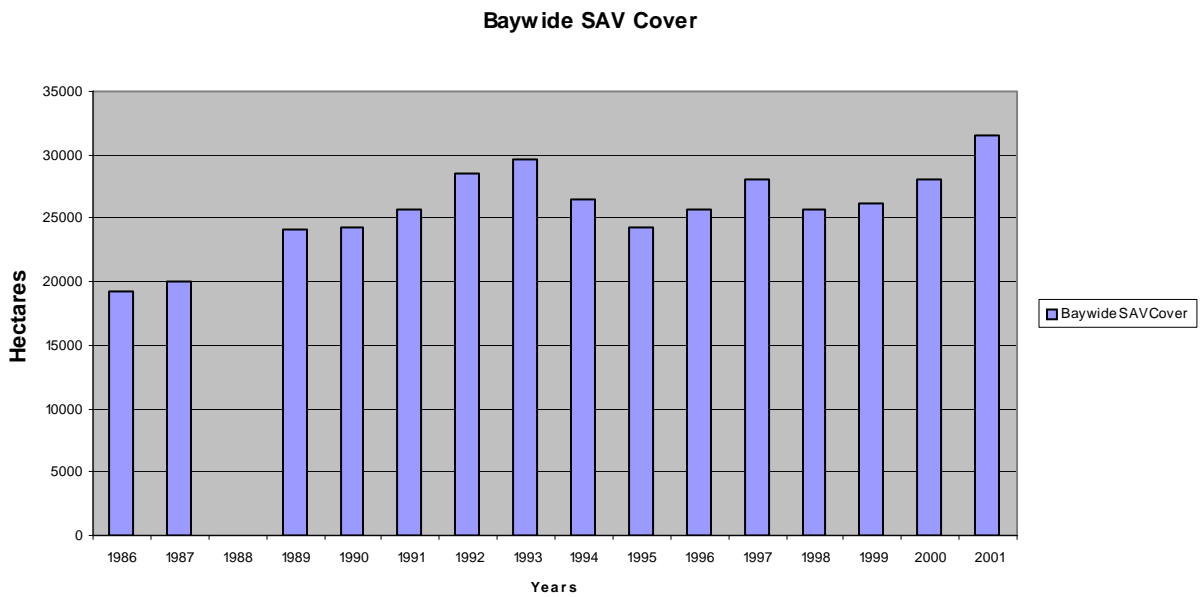
The decline in the blue crab population in Chesapeake is correlated with decline in SAV, which is the initial habitat for postlarvae. SAV cover declined approximately 70% throughout Chesapeake Bay in the late 1960's and early 1970's (Stockhausen and Lipcius 2003).

Anthropogenic nutrient inputs and increased sediment discharge from disturbed watersheds were the main reasons identified for the decline. Both phytoplankton and algae blooms from nutrients and solids reduce light availability for growth of SAV. Scientists discovered that harvesting effort (i.e. pots fished) increased synonymously as SAV decreased. This data suggests that the blue crab population may have been declining in Chesapeake Bay since the early 1970's, but the decline did not reach a critical point until the early 1990's. Relatively consistent annual yields of blue crabs were maintained throughout the decline in SAV in the Virginia hard-shell fishery (Anderson 1989, Stockhausen and Lipcius 2003).

Scientists, politicians, resource managers, and general public are working cooperatively to restore and protect SAV biomass in Chesapeake Bay, and SAV coverage has been identified as the main indicator for water quality (Orth et al. 2002). The CBP established a SAV Work Group enlisting scientists and managers to develop the Chesapeake Bay Submerged Aquatic Vegetation Management Policy in 1989. By 1992, a technical synthesis was developed on SAV that reflected improved knowledge on plant habitat requirements. As a result of these working groups and policies, phosphorus and nitrogen loads contributing to the decline in SAV have been reduced.

Solids can also be implicated in SAV decline and the presence of suspended solids is greatest in the shallow photic zone where SAV traditionally occur (Cerco et al. 2004). Models for restricting sediments loads have only recently been updated by CBP to address the increased

coastal development and alternations to the watershed (Cercio et al. 2004). Data from Virginia Institute of Marine Science (VIMS) aerial surveys indicate that SAV coverage has fluctuated and not shown a consistent increase since efforts to improve SAV abundance began in the mid-1980's (Fig. 1.) Environmental fluctuations and population increase demands require that strategies for increasing SAV coverage be continuously modified to reach conservation goals.



**Fig. 1. Baywide SAV Cover from 1986-2001.** Data for 1988 was not reported.

Juveniles and adult males are found more abundantly in unvegetated sand and mud habitats adjacent to salt marshes and tidal creeks than SAV. These areas are important for growth and development by maintaining a balance of predator-prey interactions. Water and sediment sources are being removed from the salt marsh systems by coastal development resulting in decreased productivity of benthic fauna (Lipcius, *in press*). Restoring and protecting these resources is important for maintaining a healthy stock of blue crabs. If the blue crab is

going to be sustained as a commercial fishery in Chesapeake Bay vital nursery and foraging grounds must be maintained in order to provide balance to the ecosystem.

Anthropogenic nutrient inputs have not only severely altered SAV but also contribute to increased hypoxic conditions that can significantly impair the sustainability of blue crabs as a commercial stock. The effects of hypoxia also have a negative impact on the migrating females that move reactively into shallow water where they are more available to harvesting. In upper Chesapeake Bay, seasonal hypoxia and anoxia have increased, but the impact on blue crab population is unknown. Blue crabs generally avoid hypoxic water by moving inshore and become concentrated in shallow areas (Bell et al. 2003). Cannibalism and fishing pressure increases when blue crabs are concentrated in high densities as seen in North Carolina where fisherman adjust their pots in response to hypoxic events (Selberg et al. 2001).

Lower Chesapeake Bay, where spawning grounds are located, generally incurs less hypoxia than the upper region because of considerable flushing from tidal circulation (Buzzelli et al. 2001). In 2003, water quality monitoring indicated record high levels of hypoxia throughout Chesapeake Bay (Chesapeake Bay Program 2003). Hypoxic water conditions in July covered approximately 40% of the mainstream of the estuary extending from the Patsco River near Baltimore to the York River near Hampton Roads. Heavy rains in 2003 washed nutrients into the estuary and cold-water temperatures limited mixing and exacerbated the hypoxia.

## VIII. MARINE PROTECTED AREAS

Marine protected areas (MPAs), sanctuaries, and reserves are areas designated of restricted or limited harvesting temporarily or permanently to provide protection for important habitats and species. MPAs have been shown to improve productivity of spawning stocks and recruitment of exploited species (Allison et al. 1998, Seitz, et al. 2001, Lipcius et al. 2003). MPAs may protect a significant portion of reproductive stock, and provide a buffer against natural population fluctuations and anthropogenic impacts (i.e. heavy fishing and habitat alteration). MPAs are ineffective if measures do not protect all exploitable life stages (Allison et al. 1998, Lipcius et al. 2003). The spatial and temporal design of reserves must consider episodic climatic changes and climatic events (Allison et al. 1998). Other threats such as chemical contamination may be beyond the scope of the MPA but need to be addressed by communities designing the MPA (Allison et al. 1998).

Setting appropriate objectives for MPA and making the necessary harvest limitations is also imperative to rejuvenating depleted stocks. In 1994, federal regulators closed one section of Georges Bank and two adjacent areas to year round fisheries following steep declines in heavily fished stocks, establishing the largest MPA in effect covering 20,000 km<sup>2</sup> (Fogarty and Murawski 2005). When this MPA was established, tighter fishing restrictions were implemented in locations surrounding the MPA limiting the number of hours for harvesting and trawling. By 2001, commercial and non-commercial species had sharply increased in biomass. Cod biomass increased almost 50% and scallop biomass increased 14-fold.

In addition to setting appropriate parameters for MPAs for targeted stocks, considerations to improve prey abundance needs to be considered. For example, the anadromous striped bass, *Morone saxatilis*, abundance sharply declined in the early 1980's along the mid-Atlantic bight

resulting in the U.S. Congress passing the Atlantic Striped Bass Conservation Act in 1984.

Chesapeake Bay provides nursery habitat for 70 to 90 percent of the Atlantic striped bass.

Increasing the striped bass population in Chesapeake Bay added pressure on prey species, such as the declining stocks of Atlantic menhaden and blue crab, which were not addressed when the MPA was established (National Oceanic and Atmospheric Administration 2004). Maintaining a balance of predator-prey interactions emphasizes the need for an ecosystem approach to fisheries management.

## **IX. BLUE CRAB MPA IN CHESAPEAKE BAY**

Spawning sanctuaries for blue crab have been in place in the lower Chesapeake Bay since 1941, however, the stock was not replenishing at long-term sustainable levels (Miller and Houde 1998, Seitz et al. 2001, Lipcius et al. 2003). Declines in commercial harvests in the early 1990's prompted an increase in the size of the spawning sanctuary from 378 km<sup>2</sup> to 573 km<sup>2</sup> in 1994. Despite the increase in the size, the total spawning stock declined 81% from 1992-2000 (Lipcius and Stockhausen 2002). In 2000, the spawning sanctuary was increased again to include a deepwater corridor used by females migrating to the mouth of the estuary and thereby increasing the spawning sanctuary to 1722 km<sup>2</sup>. Empirical analysis of the effectiveness of the combined spawning sanctuaries revealed that only approximately 16% of the spawning stock was protected (Seitz et al. 2001). The marine protected area and corridor (MPAC) for the spawning stock was increased to 2401 km<sup>2</sup> in 2002. The MPAC covers depths >10 m throughout the lower Chesapeake Bay from June 1 to September 15. Only female blue crabs are generally found in the deeper waters of Chesapeake Bay and, therefore, the MPA does not effect harvesting of males.

It is estimated that the MPAC could provide protection for up to 50% of the total spawning stock (Lipcius et al. 2003). However, the existing MPAC has several limitations. Displaced fishing effort around the sanctuary and seasonal protection reduce the effectiveness of the spawning sanctuary (Lipcius et al. 2003). Intense fishing efforts at the edges of sanctuaries have been observed in the Georges Bank MPAs (Fogarty and Murawski 2005). The MPAC also does not cover the spawning pulse that happens in October for females migrating from the upper estuary (Turner et al. 2003). This portion of the spawning stock is left vulnerable to intensive fishing pressure and crabbers are aware of the pulse of migrating females. Females that spawn in

the spring by overwintering at the mouth of the Chesapeake Bay are also not protected. The recruits produced by these females would be the first to return when *Z. marina* biomass is in highest abundance. Because fishing practices remove the largest crabs from the ecosystem during the time of peak mating, smaller females and males are reproducing consequently reducing fecundity (Lipcius and Stockhausen 2002, Hines et al. 2003).

Virginia trawl surveys for female abundance indicated stocks below average for 10 of the past 12 years, including 2003 (National Marine Fisheries Service 2004). Harvest takes place during the time the MPAC is open to fishing. If the MPAC were extended to provide year-round protection, females migrating from the upper estuary in October and those overwintering near the mouth, would be able to spawn in the spring. Keeping the MPAC closed to harvesting year round would likely increase fishing pressure outside the restricted area. Therefore, the action would need to be coupled with incentives that alleviate harvesting pressure or provide alternatives to harvesting.

Hatchery reared females may eventually be used for stock enhancement. Since 2001, the University of Maryland and Virginia Institute of Marine Science have orchestrated the release of hatchery-reared females and are studying the survival rate, reproduction, genetics, and contributions to the wild stock. If proven economically feasible and effective without harming the wild population, this action may be incorporated into the management strategy for blue crabs. Published research on the hatchery-reared females should be available next year.

## **X. ECOSYSTEM FISHERIES MANAGEMENT**

In 1998, the National Marine Fisheries Service's Ecosystem Principles Advisory Panel completed a report to Congress on Ecosystem-Based Fisheries Management (the Report) in response to 1996 amendments to the Magnuson-Stevens Fishery Conservation and Management Act (National Marine Fisheries Service 1998). The Report identified basic ecosystem operating principles, societal goals and management policies that could be used to evaluate and develop management practices. The Report recommended the development of Fisheries Ecosystem Plans (FEP) that could direct decisions for Fishery Management Plans for single species. In ecosystem-based management anthropogenic impacts, wants and needs, including fishing pressure, are integrated into the understanding of ecosystem structure, function and processes necessary to maintain a healthy, productive and resilient environment (Communication Partnership For Science And The Sea 2005). Based on the guidance of the Report, the NOAA Chesapeake Bay Office sponsored development of an FEP for the Chesapeake Bay.

The Chesapeake Fisheries Ecosystem Plan Technical Advisory Panel was designated to develop the FEP for the Chesapeake Bay and the prepublication is currently available from the NOAA website. The FEP incorporates an ecosystem-based approach to management defining the geological, physical and biological processes along with economic and social dimensions (National Oceanic and Atmospheric Administration 2004). The FEP presents model guidelines for multi-species ecosystem-based management in Chesapeake Bay.

The FEP has identified the (1) the major components of the Chesapeake Bay ecosystem; (2) processes important in ecosystem functioning; (3) issues relevant to fisheries; and (4) current management status for Chesapeake Bay species (National Oceanic and Atmospheric

Administration 2004). In accordance with the Report, the FEP does not give specific recommendations on individual species. FMPs should still be used for species-specific guidelines for harvesting and management practices. However, guidelines in the FEP should be incorporated into the FMPs and a precautionary approach should be applied. The precautionary approach surmises that if there is controversy over management activities then it is the responsibility of the dissenting party to prove that the resource will not be harmed by removal of the regulation (i.e. reduced harvesting levels).

Organism life cycles, food web dynamics, and habitat requirements on spatial and temporal scales for important fishery species have been incorporated into management recommendations in the FEP. Blue crabs are important both economically, supporting the most valuable fishery, and ecologically, transferring energy, in Chesapeake Bay. Habitats throughout the Chesapeake Bay ecosystem are important to supporting the various life stages of blue crabs. The blue crab is a model species signifying the importance for ecosystem-based management.

## **XI. CONCLUSIONS**

Restoring the blue crab population will require coordinated efforts from many people within the Chesapeake Bay watershed to reduce anthropogenic eutrophication and restore water quality. Recovery and sustainability of the valuable blue crab fishery hinges on protection of nursery habitat, foraging grounds and spawning grounds. Blue crabs use many different habitats throughout Chesapeake Bay, partitioned by life stage and gender. Therefore, coordinated measures to restore the population need to be in effect throughout Chesapeake Bay. The FEP has provided an avenue for coordinated efforts and detailed important ecosystem components, requirements, issues and management status for many species in the Chesapeake Bay. The success of fisheries in Chesapeake Bay depends on improved water quality. Other measures for increasing blue crab abundance in Chesapeake Bay include: (1) reversing the trend in the declining spawning stock to protect females migrating from the upper estuary and overwintering at the mouth of the estuary by extending the duration of MPAC, (2) establishing a network of MPAs to protect all life stages of the blue crab to allow some organisms to remain in the ecosystem at least through peak spawning season, (3) protection for productive nursery habitats and foraging grounds, such as unvegetated habitats adjacent to salt marshes, and (4) impose restrictions to reduce the number of crab pots, both commercially and recreationally, to increase the opportunity for blue crabs to grow and reproduce at a larger size.

## REFERENCES

Allison GW, Lubchenco J, Carr MH (1998) Marine Reserves are necessary but not sufficient for marine conservation. *Ecol Appl* 8(1):S79-S92

Anderson EE (1989) Economic Benefits of Habitat Restoration: Seagrass and the Virginia Hard-Shell Blue Crab Fishery. *North Am J Fish Manage* 9( 2):140–149

Bell GW, Eggleston DB, Wolcott TG (2003) Behavioral responses of free-ranging blue crabs to episodic hypoxia. I. movement. *Mar Ecol Prog Ser* 259:215-225

Burreson EM, Butler W, DuPaul J, Hoenig J, Lipcius R, McConaugha J (2000) The Virginia blue crab winter dredge fishery. Report of the Task Force on the Virginia Blue Crab Winter Dredge Fishery to the Governor and the General Assembly of Virginia. Senate Document No. 30:1-20

Buzzelli CP, Luettich Jr RA, Powers SP, Peterson CH, McNinch JE, Pinckney JL, Paerl HW (2002) Estimating the spatial extent of bottom-water hypoxia and habitat degradation in a shallow estuary. *Mar Ecol Prog Ser* 230:103-112

Carr SD, Tankersley RA, Hench JL, Forward Jr RB, and Luettich Jr RA (2004) Movement patterns and trajectories of ovigerous blue crabs *Callinectes sapidus* during the spawning migration. *Est Coast Shelf Sci* 60:567-579

Cerco CF, Noel MR, Linker L (2004) Managing for Water Clarity in Chesapeake Bay. *J Env Eng* 130:631-642

Chesapeake Bay Commission (2003) Blue Crab 2003: Status of the Chesapeake Population and its Fisheries. Chesapeake Bay Commission, Annapolis, MD

Chesapeake Bay Program (2003) Summer 2003 Oxygen Levels in Chesapeake Bay. Backgrounder Fact Sheet. Chesapeake Bay Program, Annapolis, MD

Communication Partnership for Science and the Sea (2005) Scientific Consensus Statement on Marine Ecosystem-Based Management. Communication Partnership for Science and the Sea, Corvallis, OR

Dittel A, Hines AH, Ruiz G, Ruffin KK (1995) Effects of shallow water refuge on behavior and density dependent mortality of juvenile blue crabs in Chesapeake Bay. *Bull Mar Sci* 57:902-916

Epifanio CE and Garvine RW (2001) Larval transport on the Atlantic continental shelf of North America: a review. *Est Coast Shelf Sci* 52:51-77

Etherington, L, Eggleston D 2000. Large-scale blue crab recruitment: Linking postlarval transport, post-settlement planktonic dispersal, and multiple nursery habitats. *Mar Ecol Prog Ser* 204:179-198

Fogarty MJ, Murawski SA (2005) Do Marine Protected Areas Really Work? *Oceanus* 43(2):1-3

Forward RB, Tankersley RA, Smith KA, Welch JM (2003) Effect of chemical cues on orientation of blue crab, *Callinectes sapidus*, megalopae in flow: implications for location of nursery areas. Mar Biol 142(4):747-756

Helser TE, Khan DM (2001) Stock Assessment of Delaware Bay Blue Crab (*Callinectes sapidus*) for 2001. Department of Natural Resources and Environmental Control, Delaware Division of Fish and Wildlife. Dover, DE

Hewitt DA, Hoenig JM (2005) Comparison of two approaches for estimating natural mortality based on longevity. Fish Bull 103(2):433-437

Hines AH, Jivoff PR, Bushmann PJ, vanMontfrans J, Wolcott DL (2003) Evidence for sperm limitation in female blue crabs (*Callinectes sapidus*). Bull Mar Sci 72:287-310

Hines AH, Lipcius RN, Haddon AM (1987) Population dynamics and habitat partitioning by size, sex, and molt stage of blue crabs, *Callinectes sapidus*, in a subestuary of central Chesapeake Bay. Mar Ecol Prog Ser 36:55-64

Hovel KA, Lipcius RN (2002) Effects of seagrass habitat fragmentation on juvenile blue crab survival and abundance. J Exp Mar Biol Ecol 271:75-98

Lipcius RN, Seitz RD, Seebo MS, Colon-Carrion D (In press) Density, abundance and survival of the blue crab in seagrass and unstructured salt marsh nurseries of Chesapeake Bay. *J Exp Mar Biol Ecol*

Lipcius RN, Stockhausen WT (2002) Concurrent decline of the spawning stock, recruitment, larval abundance, and size of the blue crab, *Callinectes sapidus*, Chesapeake Bay. *Mar Ecol Prog Ser* 226:45-61

Lipcius R, Stockhausen W, Seitz R, Geer P (2003) Spatial dynamics of the blue crab spawning stock in a protected sanctuary-corridor network in Chesapeake Bay. *Bull Mar Sci* 72(2):453-69

Miller TJ, Houde ED (1998) Blue crab target setting, final report to US EPA Living Resources Subcommittee. University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory 98-129

Moksnes PO, Lipcius RN, Pihl L, van Montfrans J (1997) Cannibal-prey dynamics in young juveniles and post-larvae of the blue crab. *J Exp Mar Biol Ecol* 215:157-87

National Marine Fisheries Service (1998) A Report to Congress: Ecosystem-Based Fishery Management. United States Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Silver Spring, Maryland.

National Marine Fisheries Service (2004) Chesapeake Bay Blue Crab Advisory Report. United States Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Silver Spring, Maryland.

National Oceanic and Atmospheric Administration (2004) Fisheries Ecosystem Planning for the Chesapeake Bay. United States Department of Commerce, National Oceanic and Atmospheric Administration, Silver Spring, Maryland.

Orth RJ, Batiuk RA, Bergstrom PW, Moore KA (2002) A perspective on two decades of policies and regulations influencing the protection and restoration of submerged aquatic vegetation in Chesapeake Bay, USA. *Bull Mar Sci* 71(3):1391-1403

Orth RJ, van Montfrans J (2002) Habitat quality and prey size as determinants of survival in post-larval and early juvenile instars of the blue crab *Callinectes sapidus*. *Mar Ecol Prog Ser* 231:205-213

Pile AJ, Lipcius RN, van Montfrans J, Orth RJ (1996) Density-Dependent settler-recruit-juvenile relationships in Blue crabs. *Ecol Monogr* 66:277-300

Ryer CH, van Montfrans J, Moody KE (1997) Cannibalism, refugia and the molting blue crab. *Mar Ecol Prog Ser* 147:77-85

Selberg CD, Eby LA, Crowder BA (2001) Hypoxia in the Neuse River estuary: Responses of blue crabs and crabbers. *North Am J Fish Manage* 21(2): 358-366

Seitz R, Lipcius R, Stockhausen W, Montane M (2001) Efficacy of blue crab spawning sanctuaries in Chesapeake Bay. *Spatial Processes and Management of Marine Populations* (Eds. Gordon H. Kruse, Nicolas Bez, Anthony Booth, Martin W. Dorn, Sue Hills, Romuald N. Lipcius, Dominique Pelletier, Claude Roy, Stephen J. Smith, and David Witherell). University of Alaska Sea Grant, AK-SG-01-02, Fairbanks

Seitz RD, Lipcius RN, Stockhausen WT, Delano KA, Seebo MS, Gerdes (2003) Potential bottom-up control of blue crab distribution at various spatial scales. *Bull Mar Sci* 72(2):471-490

Stockhausen WT, Lipcius RN (2003) Simulated effects of Seagrass loss and restoration on settlement and recruitment of blue crab postlarvae and juveniles in the York River Chesapeake Bay. *Bull Mar Sci* 72(2):409-422

Turner H, Wolcott D, Wolcott T, Hines A (2003) Post-mating behavior, intramolt growth, and onset of migration to Chesapeake Bay spawning grounds by adult female blue crabs, *Callinectes sapidus*, Rahtbun. *J Exp Mar Biol Ecol* 295:107-130

## VITA

### **Judith Gayle Pugh**

Judith Gayle Pugh did undergraduate studies at East Carolina University where she received a Bachelor of Arts in 1990. She studied a scientific curriculum from 1998-2000, with coursework from Northern Virginia Community College and George Mason University. During the summer of 1999, she completed an internship with the U.S. Fish & Wildlife Service at the Patuxent Wildlife Research Center assisting with the development of an Index of Biological Integrity for Wetlands in the Mid-Atlantic. She did this while working full time for a law firm in downtown Washington, DC. In 2001, she began working for the National Science Foundation as a science assistant for the Biological Oceanography Program. The position has offered her the opportunity to participate in two scientific research cruises. She received a Certificate of Natural Resources from Virginia Polytechnic Institute and State University in 2002.