Blue Crab (Callinectes sapidus) Ecology: Review and Discussion Regarding Tisbury Great Pond

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Blue Crab (*Callinectes sapidus*)

Introduction:
From anecdotal evidence, the population of blue crabs in the Great Ponds is highly variable over time. This is true for most locations where this crab is found. Unfortunately, there are no hard local statistics available on the population or harvest.

This crab is found primarily from Cape Cod southward although in mild years it will be found off the Maine Coast and even in Nova Scotia. A large amount of research on the crab has been done for the Chesapeake Bay area and in the coastal embayments further south along the western Atlantic Ocean and in the Gulf of Mexico. The Chesapeake Bay probably serves as a good basic model for identifying the factors that affect the crab population from year to year because of its distinctly estuarine nature, similar water temperature and proximity to the Vineyard.

On the Vineyard, the crab is somewhat more of a south shore pond denizen although it is found along the north shore ponds particularly Trapp's Pond at the inner reaches of Sengekontacket Pond on the Edgartown end. The tidal connection between Trapp's and Sengekontacket under Beach Road has long been called Crab Creek due to the abundance of blue crabs found there. This distribution probably relates to the crabs preference for estuarine water characteristics that are common to the Great Ponds either due to their large stream inputs (Tisbury Great) or their predominance of groundwater input while they are closed to the ocean. The south shore ponds provide the salinity range and possibly warmer water temperatures that are suited to blue crabs.

Attached to this report are four appendices that contain more detailed information about the blue crab. These include extracts taken from websites that have extensive information on blue crab biology and ecology in Appendix A. Appendix B contains an annotated bibliography of technical reports on crab studies carried out by researchers that make relevant points about the population ecology of the crabs. Appendix C contains information on crab population both anecdotal information for the Vineyard and hard data from elsewhere. Appendix D includes information on crab aquaculture.

Relevant aspects of the life cycle:
Blue crabs are characterized as an "r" category strategist in their reproductive ecology. They produce huge numbers (1 to 2 but up to 8 million eggs per female) of offspring that grow quickly and become sexually mature rapidly. This type of species is subject to wide swings in abundance due to chemical, physical or biological factors (website information, Appendix A). It is normal for wide variations in the numbers of this type of animal from year to year.

Mating occurs anytime from May to October (in the Chesapeake) in lower salinity waters in marshy areas while the female is in the soft stage after shedding her shell. Once mated female crabs may hold the sperm in a specialized receptacle for several years. The females may produce and fertilize eggs more than once each year and over two or more seasons. The first spawning usually occurs 2 to 9 months after mating. This provides them with the ability to wait for a suitable time to produce the next generation, allows a second spawning if the first fails and spreads the production of offspring over a long period of time.

Once produced and fertilized, the eggs develop over a 14-day period. In the Chesapeake, the eggs hatch on an ebb tide where salinity is 20 parts per thousand (ppt) or more. In the case of the Great Ponds, this means that the crabs may wait for an inlet to be cut to exit the pond and then produce their eggs outside or the eggs may be produced in the pond once an inlet is cut or before the inlet is cut at risk that the larvae will hatch before the required salinity is available. Peak spawning in the Chesapeake occurs over a short period in June, and again in July/August**.**

From anecdotal information (Appendix C), egg-bearing females are seen in the pond along the barrier beach before an inlet is cut. In that situation, either **a delay in cutting the inlet or a failed inlet may stimulate crabs to produce eggs but not allow the larvae to escape the pond leading to reproductive failure due to salinity below 20 ppt.** However, the ability of the females to produce another generation the same year reduces the overall impact of this eventuality. I could not find information on the fecundity of the females for subsequent reproductive efforts. It may be that when producing a second brood, the hatch is smaller and the physical effort may weaken or stress the female crabs setting the stage for predation or disease.

In the Chesapeake, the larvae (called zoeae) exit with the ebb tide and spend 30 to 45 days on the inner continental shelf passing through a number of life stages in the planktonic community. The final stage is only 1 millimeter wide. They then metamorphose into the megalopae stage. This stage is capable of swimming to the surface at night and downward during the day. At the right time it migrates vertically in the water column to ride wind driven currents as well as flood tide waters back into the Bay. There they look for an opportunity to settle into aquatic vegetation. The megalopae stage lasts 6 to 20 days. At the end of this stage, the megalops molts into a juvenile crab (J1 stage) that is about 2.5 millimeters across. It is likely that the crabs we recruit while a summer inlet is open originated from other ponds possibly quite remote from the Vineyard. The combination of prevailing southwest winds, northward flowing Gulf Stream as well as eddies and gyres that break loose from the Stream could transport them from several hundred miles away during the 50 day plus or minus planktonic stage.

The male juvenile crabs eventually migrate into shallower, fresher water. Both sexes go through a number of molts to mature at 12 to 18 months age. I suspect that once crabs are recruited to a pond, they remain in that pond throughout their life.

One population bottleneck that jumps out as a potential controlling factor in the Great Ponds is the availability of an inlet during the time when the megalopae stage is looking to return to the pond from the nearby shallow shelf waters. Researchers have found that the megalopae come into the Chesapeake in pulses and much of the recruitment for a given year may happen over one or two periods of less than a week duration. In the case of our south shore ponds, if there is no inlet at the required time, the recruitment for that year may be small. This eventuality is somewhat overcome by the prolonged spawning period that leads to megalopae availability in the shallow shelf water for an extended period of time although perhaps at less than peak numbers for a large portion of that time.

Other factors affecting population:
Prolonged water temperature around freezing has been found to cause young crab die off in Barnegat Bay (Reference #11, Stehlik et al, 1998, Appendix B). Adult crabs have also been winter killed in the Delaware and Raritan Bays in 1996 but this is rare. Late spring cold snaps after the adults move out of the deep-water wintering sites might have a substantial impact (reference #1 Van Engel, Appendix B).

Water temperatures over 91 degrees F are lethal. These are not likely to occur other than in a few isolated shallow areas or in the surface few inches of the pond. Last summer (2003), the water temperature approached 80 degrees F well short of the lethal temperature. An examination of data from the past three years indicates that 80F is probably the maximum temperature occurring in July or August in most years.

Crabs are omnivorous in their food requirements including oysters, other mollusks, detritus, algae, fish and each other. Oyster decline or die off may have some impact on crab population but food in the Great Ponds in general is probably not a major population control.

Crabs can tolerate or evacuate from areas where there are low dissolved oxygen levels. It is doubtful that a short duration anoxic event like last year's would have a serious impact on the population (website information in Appendix A).

A lack of bottom vegetation exposes the crabs to predation during the juvenile stages and when the adults are molting (Reference #13, Appendix B). Tisbury Great Pond has little eelgrass at this time but it does have areas dominated by algae including Ulva, pondweed and tape grass primarily at mid-depth (less than 2 meters) in the pond. During years where there is less bottom vegetation, heavy predation of blue crabs might reduce the adult population. These predators include striped bass, eel, other blue crabs and heron. If larvae are produced in the pond, herring could also be a factor. Striped bass feed on blue crabs although there is some indication that crustaceans only comprise about 5 percent of their diet (Maryland DNR, Fisheries Technical Memo Series #2, January 1993). If trapped in the pond by a closed inlet, they could exert particular pressure on the crab population.

There are a number of parasites and diseases that affect the health of crabs (Reference #9, Appendix B). It appears that diseased animals become prey for other crabs or predators and do not survive long enough to show particularly clear symptoms. Environmental stress may play a role in predisposing animals to infection.

It is possible that there are blooms of phytoplankton that may impact the population- not in terms of crab diet but by the toxins contained in the bloom. This would be more of an issue if the larvae that feed on plankton remained in the pond. We have phytoplankton identification information from 1995 and 1997. I do not believe there were any "toxic" blooms during that time frame.

Possible Great Pond blue crab population model:

- In late spring and through the summer, mated female crabs move from the lower salinity parts of the Great Pond system to the saltier areas i.e. toward the barrier beach or nearby areas that maintain salinity like the mouth of Deep Bottom Cove. Some produce egg masses at risk of failure if an inlet does not become available to allow the larvae to exit the Pond and the salinity falls below 20 ppt.
- Eggs are hatched with the goal of delivering the larvae to the Atlantic. This can happen either by being offshore when the eggs hatch or being near the inlet to release larvae that move out to the Atlantic with the net ebb flow. If, at the time the mated crabs arrive an inlet exists or is soon cut, they either exit the pond and produce eggs offshore or produce the eggs in the pond system. They desire 20 parts per thousand or greater to initiate this process as this is required by the larvae. If hatched in the Pond, release of larvae that successfully emigrate to offshore waters is limited to the lifetime of the inlet. Long lasting late spring and summer inlets may allow hatches to occur in the pond that succeed in exiting the system.
- Recruitment size is a function of the presence of an inlet at the time a significant larval patch exists offshore. Long lifetime late spring, summer and early fall inlets set the stage for significant recruitment. Southwest winds prevail during the summer and should move new potential recruits in-shore from their shallow shelf development area. The megalopae stage is capable of swimming and can move up into shallow water to ride the wind driven surface currents into the system with flood tides. Recruited crabs undoubtedly include the descendants of adults that originated in other ponds and, in the 40 to 60 day planktonic stage, may have drifted from far away.
- Once recruited the success of the recruits in building the adult population is affected by predation that is related to the availability, density and type of vegetation cover. Juvenile crabs probably complete their growth to adult in 12 to 18 months within the Pond. It appears unlikely that they would exit before reaching the adult stage.
- The crabs are probably permanent residents of the pond. The males prefer low salinity water and probably do not exit the system. If the females exit to produce eggs or during the hatch, they probably return to the same pond.

Reports of adult crabs entering Edgartown Great Pond from offshore during an inlet raise the intriguing possibility of either an offshore resident or transitory population (possibly crab movement from one pond to another). Addition of adults from offshore may add substantially to the pond population.

The primary population size determinant appears to me to be the successful recruitment of new crabs. The population would be large in the year(s) following the coincidence of either:

1. A long-lived inlet that allows ingress for a prolonged period and encourages either multiple entrance of pulses of crabs or continual entrance at a steady rate.
2. The coincidence of an existing inlet with the presence of a megalopae patch that allows a short-term, high rate of recruitment.

Factors that would lead to increased crab populations:

1. Increase the lifetime of summer inlets to allow more time for a chance to “catch” a larval patch.
2. Time an inlet to coincide with the late-August peak recruitment found elsewhere. (**Note**: we don’t have any data to indicate when the Great Pond recruitment occurs. So this is a hypothetical timing until there is data available).
3. Increase submerged aquatic vegetation in recruitment areas. This would include eelgrass on the inside of the barrier beach and pondweed and widgeon grass further into the coves. A more detailed survey of vegetation type, distribution and density is probably a needed first step to assess the potential benefits form a large, costly effort like this.
4. Stock the pond(s) with hatchery raised juvenile crabs (See Appendix D).

Of these, only numbers 3 and 4 are “within our control”. Number one is completely dependent on wind and weather conditions at the time an inlet is cut and in the following weeks. Number two is somewhat more in our control but depends on the pond level being high enough to allow a successful cut.

Research that would help improve our understanding of the crab life cycle and other factors in their population dynamics:

- Plankton tows in the inlet channel during peak flood tides to estimate quantity and timing of recruitment.
- Adult and juvenile crab population density and distribution estimates by catch and release trapping.
- Mapping of type, distribution and density of aquatic vegetation in the Pond.
- Identify habitat areas used most heavily- Black Point Pond and the Coves

Recent blue crab population decline:

It is reported that blue crab populations declined in Tisbury Great Pond during the years 2001 through 2003 (see notes at beginning of Appendix C). This coincides with lower populations in Chesapeake Bay since 1998 at densities that are about 40 to 50% below previous years population density (1990 to 1997; see Tables on page 18). The Data shown in these Tables is graphically displayed in Appendix C in the second section labeled “Winter Dredge Survey”. See in particular Figures 1, 3, 4, 5 and 6 where the density estimates for different ages and sexes are all markedly lower since 1998. The VIMS trawl survey is also included although the data is included in the Winter Dredge Survey data. The VIMS population indices are also lower since 1995 for all ages.

A decline in crabs in Tisbury Great Pond could result from fewer crab larvae available for recruitment due to fewer spawning females in the Chesapeake and nearby bays that are the source of our recruits. The decline could relate to a widespread cycle in the conditions necessary for successful population development. There could be pond-specific causes associated with decrease in cover, increase in disease or predation. The range of possible causes is large.

Harvest data is reported in Appendix C from the National Marine Fisheries Service for the Mid-Atlantic States and for the Chesapeake Bay States. In the Mid-Atlantic States, the harvest is down by about 23 percent for the period between 1996 and 2002 (average of 10,115,309 pounds) compared to the previous 6 years (average annual take of 13,217,058 pounds). In the Chesapeake, the harvest from 1998 and particularly for 2000 through 2002 is less than in the 1990 through 1995 period but it is difficult to discern a trend.

Blue crab aquaculture:
For a number of years, Japanese hatcheries have raised and released millions of swimming stage crabs of a species that is related to the blue crab. The success of these hatchery reared juvenile crabs after release has not been documented. Research is underway at the University of Maryland Center for Marine Biotechnology to identify hatchery requirements for rearing blue crab to the juvenile crab stage. In the first years, optimized diet produced up to 70 percent survival rates. Artificial structures appear to help to reduce cannibalism and lower mortality rates by providing cover. COMB researchers found that the hatchery-reared larvae reverted to natural prey with no apparent difficulty and grew to 5-inch size when tagged and followed in the wild. This study followed the juveniles for 14 weeks in the wild indicating the success of the program. See Appendix D for relevant information.

A blue-crab stocking program for local ponds with hatchery-raised crabs might be worth further consideration. A two-pronged project consisting of working out hatchery requirements and creation of a local market would be necessary. Use of a portion of existing hatchery facilities could allow an inexpensive, small-scale trial. A meeting with local fishermen, restaurant owners, Shellfish Wardens, MV Shellfish Group and Division of Marine Fisheries personnel would be a first step.

APPENDIX A
Website Information on Blue Crabs

Blue Claw Crab: Callinectes sapidus--WEBSITE INFO (references-page 17)

Sections highlighted in bold, blue italics represent my thoughts and speculations.

Life Cycle[1]:

- In the Chesapeake Bay, blue crab larvae–called *zoeae*–are released by mature females in high salinity waters near the mouth of the Bay. The zoeae are transported to the continental shelf, where they develop for a period of 30 to 45 days, through seven or eight distinct stages. The shrimp like zoeae feed on zooplankton and plant material.

Note: Crabs gathering near the south shore is part of this process of seeking higher salinity water for larval release. The effect of delayed summer opening maintaining low salinity water is not known although females can delay egg production. The potential exists for the duration and timing of an inlet through the barrier beach to have some effect on the reproductive success of a crab generation(s).

- Zoeae change to the post larval–*megalopae*–stage on the near-shore Atlantic shelf.

Stage 1: First stage larvae, called **zoeae**, measure approximately 0.25 mm at hatching. They bear little morphological resemblance to adults (Hopkins 1943), are filter feeders, and live a planktonic existence in the high-salinity surface waters near the spawning grounds (Pyle and Cronin 1950; Darnell 1959). Tagatz (1968) found more zoeae near the water's surface than at the bottom. Evidence suggests that blue crab zoeae hatch in the Chesapeake Bay, Chincoteague Bay, Delaware Bay, and other estuaries and drift out to sea, where they feed and grow. These larvae may migrate vertically in the water column to reach flood and ebb tides, which transport them back into the bay area.[4]

The zoeae and all subsequent life stages can increase body size only by molting (Hay 1905; Pyle and Cronin 1950). Zoeal development may require 31 to 49 days, depending on salinity and temperature, but development time has been shown to be variable even in a single salinity-temperature regime (Williams 1965). Zoeae molt four to seven times before entering the next stage of development. The final zoeal stage is about 1.0 mm in width (Hopkins, Rogers 1944). [4]

Zoeal stage.

Stage 2 - Megalops

The final molt of the zoeae is characterized by a conspicuous change to the second larval stage, called a **megalops** (also termed **megalopae** [singular] or **megalopae** [plural]. Development to this stage requires 31 to 49 days. The megalops larva is more crablike in appearance than the zoeae, its carapace is broader in relation to its length, and has biting claws and pointed joints at the ends of the legs. It measures about 1.0 mm in width. The megalops swims freely, but generally stays near the bottom in nearshore or lower-estuarine, high-salinity areas (Tagatz, 1968). The megalops stage lasts 6 to 20 days, after which the megalops molts into the "first crab" stage,

Megalopa - Post Larval Stage
Photo courtesy of Alicia Young-Williams, Smithsonian Environmental Research Center

like those of an adult.

There are usually seven zoeal stages and one post larval, or megalopal, stage. On occasion, an eighth zoeal stage is observed.

- Once they have been swept into the Bay by wind and currents, megalopae migrate vertically in response to light and tide. They use nocturnal flood tides to assist their movement up the estuary to shallow estuarine nursery habitats.
- Megalopae settle in the lower Bay and use SAV beds as nursery beds. After six to 20 days (and depending on salinity and temperature), the megalopae molt producing the true first crab stage. It is at this time that they become recognizable as miniature blue crabs.

The juvenile "first crab" is typically 2.5 mm wide (from tip to tip of the lateral spines of the carapace). These juveniles gradually migrate into shallower, less-saline waters in upper estuaries and rivers where they grow and mature (Fischler and Walburg 1962). Van Engle (1958) and Tagatz (1968) reported that many juveniles had completed this migration by fall and early winter. New evidence, however, suggests the bulk may not reach the upper parts of tributaries and Chesapeake Bay until the following summer.[4]

Males generally migrate farther upstream, preferring low-salinity waters, whereas females tend to stay in lower rivers and estuaries (Dudley and Judy 1971; Music 1979).[4]

- Blue crabs mature at approximately 12 to18 months of age. Under current levels of fishing pressure, most crabs live from one to two years beyond maturity and the typical lifespan of a crab is up to three years. The maximum age may be as long as five to eight years.
- The sexually mature crab is approximately five inches wide–the legal size for harvesting.
- Before mating, the male "cradles" the female in its legs and carries her for up to several days while searching for suitable cover, where he guards her during her final molt. Mating takes place while the female is in her soft-shell phase. Mating occurs primarily in relatively **low-salinity** waters in the upper areas of estuaries and lower portions of rivers. Mating takes place in areas where female crabs normally go to molt—shallow areas with marsh lined banks or beds of submergent vegetation. Blue crabs mate in the Chesapeake Bay from May through October. After mating, the male resumes cradling the female for several more days until the new shell has hardened. The male departs to search for another receptive female; the female migrates to the higher salinities of the lower Bay, where she develops an orange external egg mass beneath her apron that may

contain between 750,000 and 8 million eggs, depending on her size. Studies in Florida found that some female crabs produce as many as seven broods (sponges) in one year from a single mating, and up to 18 broods over 2 - 2½ years. Chesapeake Bay female crabs are capable of producing multiple egg masses over several years, though most will not produce more than one or two masses due to their short average life span, typically 1 - 2 years.

- The egg mass darkens over a two-week period as the orange yolk is consumed by the developing larvae. Larvae develop large black eye spots as hatching approaches.

Spawning is protracted and occurs over a period of one to two weeks. Spawning occurs from May to September, with a minor peak in June and major peaks in July and August. Unlike most marine organisms, **blue crabs mate and spawn at <u>different</u> times.** During mating the male crab transfers his sperm into special sac-like receptacles in the female crab. These receptacles store the male's sperm so that it can be used for egg fertilization at a later time. Viable sperm can live in the female's seminal receptacles for well over a year and will be used for two or more spawnings. The pregnant blue crabs will spawn for the first time 2-9 months after mating, usually from May through August the following season (they over winter before spawning by burrowing in the mud.)

- Individual females may spawn more than once, depending on the amount of sperm transferred during mating.
- Successive spawns may occur during the same year, or females may over winter before spawning again the following spring.


Female with egg mass.

Molting[3]:

Precdysis (pre-molt or "peeler" stage)

- Molting hormones are released.
- The **hypodermis** detaches from the existing hard shell. The **hypodermis** is a layer of cells directly beneath the shell.

- The hypodermis produces **enzymes**, which begin to **dissolve** the shell components. Much of the existing shell is **recycled** causing it to become thin. Inorganic salts are resorbed from the shell and stored internally.
- A new inner "soft" shell slowly forms underneath the existing shell. When this new shell has fully formed, the crab will be ready to molt.

Ecdysis (molting or "busting" stage)

- The crab stops eating and seeks shelter in order to avoid predation. During this process the crab is highly vulnerable to predators, including the two-legged variety!
- The crab rapidly absorbs water that causes its tissues to swell and split the old shell open across the back between the lateral spines. Fracture planes in the claws split open to allow the claws to be pulled through.
- The crab begins a slow, arduous, process of backing out of its old shell, which is then discarded.
- The newly molted crab pumps water into its tissues in order to inflate the new shell to its new size. The new shell will be roughly **one-third larger** (33%) than the old shell. The new shell reaches its full size within six hours after molting.

Postecdysis (postmolt or "soft crab" stage)

- The salvaged inorganic salts are rapidly redeposited to help thicken and harden the new shell. The new shell will only harden in water (the hardening process stops if the crab is removed from the water) and will take approximately two to four days to fully harden.

Over time, as the crab slowly grows inside its new shell, tissue water is replaced with protein. Once there is no more room left to grow inside this shell, the whole molting process starts over again.

Population cycles are influenced by:

Blue crab population abundance can fluctuate dramatically from year to year. The blue crab is an "r" (reproductive)-selected strategist species, which is characterized by production of large numbers of young, rapid growth, early attainment of sexual maturity, high mortality rates, and short life span. Such species exhibit large interannual fluctuations in abundance because physical, chemical, and biological factors strongly influence abundance. In addition, blue crabs populations are cyclic. Five-year and longer cycles have been identified.[5]

Climate: ***Climate change in our area is producing a gradual average warming. Sea level continues to rise at about 1 foot per century with half being the result of melting polar ice and half due to crustal subsidence. As the blue claw crab is a southern species, a warming climate in itself should not be an on-going negative factor in population change. Rising sea level will gradually shrink the size of the great ponds***

but over the foreseeable future this should not reduce habitat in the coves. It may cause Black Point Pond to be isolated from the Great Pond and be lost as crab habitat.

<u>Habitat Change:</u> ***Submerged aquatic vegetation is important to the megalopae and juvenile stages that uses these beds as nursery sites. The loss of aquatic vegetation beds would expose this stage to greater predation lowering survival rates and impacting crab populations in subsequent years. While we strongly suspect eelgrass beds were more extensive in the pond in the past (and still occur to a limited extent), we do not know when they were reduced to the present levels. Presence and density variations from year to year of widgeon grass, pondweed, large drift algae and other rooted macrophytes that provide habitat and cover are also not known.***

<u>Environment</u>

1. Water Temperature[4]

Water temperature requirements vary and are considered important, but no optimal range is reported.

When air temperatures drop below 50 °F (10 °C), adult crabs leave shallow, inshore waters and seek deeper areas where they bury themselves and remain in a state of torpor throughout the winter. Blue crab growth is regulated by water temperature. Growth occurs when water temperatures are above 59 °F (15 °C). Water temperature above 91 °F (33 °C) is lethal. Blue crabs are susceptible to sudden drops in temperature.

While commonly thought of as a more southern species (south of Cape Cod), blue claw crabs are found as far north as Nova Scotia but usually only after several consecutive warmer-than-normal winters. Populations in the Great Ponds may suffer greater mortality during particularly harsh winters. High temperatures in the pond are typically well below 30 degrees C but localized areas may exceed that value and may impact crab populations.

2. Water Salinity[4]

Salinity is important, but requirements vary by life stage. Generally optimum is 3-15 parts per thousand (ppt). Salinity of over 20 ppt is required for the larval zoeae stage. Females seek this salinity level to spawn.

It would be highly unusual for the salinity in the main basin of the Pond to approach 3 ppt but the heads of the coves fall into this range on a regular basis. However, salinity is often less than 20 ppt. The pond itself is not suited to successful development of larval stage crabs. They need to get out to the ocean if they are hatched in the pond.

3. Water pH[4]

Tolerance range is pH 6-8. Less than 6 is lethal.

This is probably not a factor except possibly in the freshest portions of the coves. When there is any salinity in the water column, the water pH is almost always at or above neutral. However, we have very little data on pH.

4. Food[4]

Adult blue crabs prefer mollusks such as oysters and hard clams as their primary food sources. The crab uses the tips of its front-most walking legs to probe the bottom for buried bivalves and to manipulate them after they are located. Some other common food items include dead and live fish, crabs (including other blue crabs), shrimp, benthic macro invertebrates, organic debris, and aquatic plants and associated fauna such as roots, shoots and leaves of sea lettuce, eelgrass, ditch grass, and salt marsh grass. It will also prey on oyster spat, newly set oysters and clams, or young oysters and quahogs if other food is unavailable.

The wide diversity of food consumed, reduces the likelihood that lack of food impacts the population. Oyster population decline could have some effect on crab population size by reducing the availability of a favored food.

Juvenile blue crabs feed mostly on benthic macro invertebrates, small fish, dead organisms, aquatic vegetation and associated fauna.

Zoeae are phytoplanktivorous and readily consume algae, phytoplankton and zooplankton. Megalopa are considered general scavengers, bottom carnivores, detritivores, and omnivores. Megalopa are more omnivorous than zoeae and prey upon fish larvae, small shellfish, and aquatic plants.

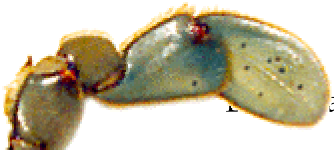
We only have limited information on the types of plankton found in the Pond and nearshore areas (1995 and 1997 data). In the instance that a generation is hatched in the pond and remains for some time until the inlet is cut, it is possible that unsuitable plankton populations may dominate during a particular year causing a food shortage or that some varieties that contain toxins may reduce palatability or cause health impacts and decrease the success of the hatch.

Dissolved oxygen variations: **See reference #15 in Appendix B.** ***Last summer we appear to have had an anoxic event in the pond sufficient to be the possible cause of a large number of dead oysters. While crab mobility should be adequate for them to escape to oxygenated waters, this kind of event might impact population. Crabs in the Chesapeake carry on a so-called crab jubilee when low oxygen drives them out of the water to the shoreline and up onto buoys and other floating objects. This behavioral capability would argue against an apparently short-duration event as we experienced having a major negative effect on crab population.***

Disease: ***The presence of diseases in the blue claw crab population in the Pond is not known.***

"Pepper Spot" Disease[2]

The meat of an infected crab appears to be peppered with small dark spots, which indicate that it is infected with parasites (called buckshot or pepper crabs by some watermen). Although its appearance may be unappetizing, the cooking process kills the parasites and renders the crabmeat completely safe to eat.



More scientifically, the crab contains the microphallid fluke (*Microphallus basodactlyophallus*), which has been hyperparasitized by a haplosporidan protozoan (*Urosporidium crescens*). The minute, brownish, protozoan infects the tissues of the encysted worm and undergoes extensive multiplication until the cyst increases in size by many times and the worm's tissue has been replaced by spores. The vast number of spores in a cyst distinguishes each cyst as a visible black speck.

The disease is spread by any of four species of snails, which are found in shallow low-salinity estuaries. The infected snails release the infective free-swimming larva (*cercaria*) which penetrate the crab. Many crabs are infected with the fluke, which can barely be seen without a microscope. It isn't until the fluke itself becomes infected with the protozoan hyperparasite, becoming visible, that people exhibit apprehension. (Jeff Shields, VIMS).

See also Appendix B notations on Noga research paper.

Harvest:

We don't have any information on the harvest of blue claw crabs. The harvest is probably all recreational. It would make sense to be sure that the public is aware of the requirement to leave egg-bearing females in the pond.

7. Abundance & Predation:

Immediately after molting, crabs are vulnerable to predators because they are soft, so they often hide in Bay grass beds for protection. Young crabs use Bay grass beds for nursery areas, and crabs of all sizes forage for food there. Bay scientists have found that 30 times more young crabs were found in Bay grasses than in areas without grass[1].

Loss of cover exposes crabs to greater predation pressure.

Predators of blue crabs include fish as well as other blue crabs. In the Chesapeake, the major fish predators of blue crabs in both their post larval and juvenile stages include the Black Drum, Red Drum, the American Eel, Striped Bass, Spot, Sea Trout catfish and the Atlantic Croaker. Some sharks and cownose rays feed on juveniles and larger crabs. The Atlantic Ridley sea turtle, an endangered species, migrates to Chesapeake Bay every summer to find its preferred food, the blue crab[1].

Of these, eel and striped bass occur in the pond. Heron also feed on crabs and are common to the Pond. Population size of predators within the pond system will impact crab populations. Stripers trapped in the pond would seem to have the crabs in a fish-in-a-barrel situation.

In general, from a comparison of Striped bass stock estimates that have risen steadily from 1982 through 1999 with blue crab landings in the Chesapeake, there is only a limited correlation between increasing bass population and reduced crab landings. The Chesapeake crab landings oscillated between 57000 metric tons and 85000 metric tons over the 1988 through 1999 period without apparent response to predation pressure by the increasing bass population.

Predators claim large numbers of young crabs, and crab populations may vary from year to year according to the abundance of predators. Blue crabs are subject to predation throughout their life cycle and are particularly susceptible when they are soft during the molting process.[4]

As larvae, they are vulnerable to fishes, jellyfish, shrimp, and other planktivores. Plankton feeders eat the larvae as they drift in the water; after they settle, eel, drum, striped bass, sea trout, catfish, spot, and other blue crabs* are primary predators.[4]
Herring are plankton feeders and may impact crab populations during the larval stage but only if the crab larvae are hatched in the pond.

The megalopae and juvenile crabs are consumed by various fishes and birds, as well as other blue crabs*.

Adults are consumed by other blue crabs*, American eels, striped bass, Atlantic croakers, cobia, red drum, black drum, oyster toadfish, sandbar sharks, bull sharks, cownose rays, speckled/spotted trout, weakfish, catfish, gars, largemouth bass, loggerhead turtles, Atlantic Ridley turtles, herons and egrets, various diving ducks and raccoons.

> *The blue crab is well known for its cannibalistic habits. Cannibalized blue crabs make up as much as 13% of a crab's diet. Blue crabs in poor health, missing important appendages, heavily fouled with other organisms, and those during or immediately following molt are more likely to be cannibalized.

Growth of fouling agents such as algae, sponges, polysiphonia etc. may be stimulated by the nutrient content of the pond and lead to years when cannibalism has a larger impact on mortality.

WEBSITE FOOTNOTES:

1. www.fisheries.vims.edu
2 www.blue-crab.org/crab_disease
3 www.blue-crab.org/molting.php
4 www.blue-crab.org/lifecycle1.htm
5 www.blue-crab.net/bchist.htm

Chesapeake Crab Population:
Virginia Institute of Marine Science Trawl Survey (see Appendix C for more detail)

Total mean crab densities are calculated for every year of the winter dredge survey. The table below presents total crab densities for years 1990 to 2003. See Appendix C for associated text and for a key for the age of the blue crabs in the mean crab density table below (**T = Total Crabs/all age classes**). The mean crab density is measured in the number of crabs per 1000m^2, so the mean abundance of total crabs (T) in 1990 is 82.16 crabs per 1000m^2.

Bay-Wide mean blue crab densities for each age category											
Year	T	T0	T1	T1+	T2	M0	F0	M1	F1	M2	F2
1990	82.16	47.34	16.97	34.82	17.85	26.53	21.99	11.69	5.89	8.84	9.01
1991	85.53	36.43	18.38	49.11	30.73	20.13	19.41	13.61	6.04	12.14	18.59
1992	38.14	10.69	7.06	27.44	20.38	4.98	5.54	4.34	2.73	4.86	15.52
1993	88.32	51.27	24.63	37.05	12.42	25.03	25.05	11.95	8.56	6.21	6.21
1994	53.55	30.94	8.77	22.61	13.84	15.38	15.83	6.08	2.85	4.56	9.28
1995	50.43	30.71	11.35	19.72	8.37	13.13	15.37	6.24	3.75	4.01	4.36
1996	76.50	51.82	9.31	24.68	15.37	25.37	26.53	5.60	3.71	5.30	10.07
1997	69.76	52.16	6.71	17.59	10.88	24.01	27.97	3.95	2.73	3.40	7.48
1998	36.43	16.87	7.38	19.54	12.16	7.54	9.34	4.40	2.98	3.89	8.27
1999	31.93	22.76	2.43	9.17	6.74	9.58	13.19	1.21	1.21	2.01	4.73
2000	30.49	13.90	3.77	16.59	12.82	6.45	7.44	2.31	1.47	2.11	10.71
2001	26.64	15.86	4.11	10.76	5.70	7.05	7.40	2.65	1.96	1.93	4.24
2002	32.35	19.81	3.68	12.54	7.29	7.25	9.79	2.85	1.47	3.82	4.40
2003	39.80	17.88	9.32	21.91	12.59	9.53	8.35	5.97	3.35	7.90	7.69

Table 5. Annual estimates of over-wintering abundance (in numbers) of blue crabs in Chesapeake Bay, 1990 – 2002.

Year	Abundance
1990	806,365,071
1991	839,440,172
1992	374,327,700
1993	866,822,822
1994	525,570,224
1995	494,948,765
1996	750,814,605
1997	684,664,403
1998	357,446,639
1999	313,379,220
2000	299,246,239
2001	261,460,145
2002	317,501,340
2003	390,619,886

Source: Maryland Winter Dredge Survey
http://www.dnr.state.md.us/fisheries/crab/winter_dredge.htm#MEAN CRAB DENSITY:

APPENDIX B
Annotated Bibliography on Blue Crabs

1. **Van Engel, Willard (~1985) Laws, Regulations and Environmental Factors and Their Potential Effects on the Stocks and Fisheries for the Blue Crab in Chesapeake Bay Region 1880 –1940 SRAMSOE #347, VIMS: VSG #99-07**

Storms: Passage of severe storms in 1901-02, 1935-36 and 1939-40 are correlated with large numbers of dead crabs in 1939-1940 and low catches in 1902, 1936 and 1940. Damage to female crabs by waves and currents driving them over sand bottoms are discussed as a possible cause.
Temperature: Speculation that crabs moving out of deeper waters in late winter/early spring are caught by cold snaps. Some evidence that adult females do not tolerate extreme cold when combined with low salinity. There was a correlation ($r^2 = 59\%$) between May Cooling Degree Days (CDD, the sum of the departures between mean daily air temperature and 65 degrees F) and Biological Year Landings. High CDD in May combined with high surface water temperatures correlates with successful fishing that year.
Rainfall: Speculation that the amount of rainfall determines the input of nutrients and the plankton population as a food source as well as the required salinity zone location and the size of this habitat space for juvenile crabs. Juvenile crabs move up into fresher waters in the fall and develop rapidly in the spring period of maximum river discharges. Low rainfall (less river flow) would correlate with decreased space and increased competition. High rainfall leads to more food and more appropriate habitat space. The conclusion is that rainfall is a factor but not a critical one with the possible exception of extremes.
Submerged Aquatic Vegetation (SAV): Speculation only that changes in the area covered by SAV might correlate to crab populations.
Continental Shelf Circulation: Some evidence of a correlation between shelf circulation and movement early life stages into the Bay.

2. Smith, D. and M. Knappenberger Blue Crab Recruitment Dynamics in Chesapeake Bay: A Review of Current Knowledge. Virginia Sea Grant: VSG-89-01
In the Chesapeake, mating peaks in late August and early September. Once mated, females migrate to the mouth of the Bay. Similar migrations are found in Louisiana, Florida and North and South Carolina. Egg stage lasts 10 to 17 days depending on salinity and temperature. There is some circumstantial evidence of a synchronized hatching along with a nighttime ebb tide. First stage zoeae migrate to the surface. Zoeae survive and molt at salinity over 20 PPT and temperature of 20 to 30 C. Beyond the first of seven larval stages the salinity requirement increases. The Zoeae stage lasts 30 to 60 days. The post-larval megalopae has an optimum salinity requirement of 30 PPT. This stage lasts about 40 days on average and is also affected by temperature and salinity. The first stages may be found in or near the Bay mouth but the later stages are found further offshore. Wind driven circulation is important in the movement of the larval and megalopae stages. The megalopae move back into the Bay and settle to the bottom between August and May in episodes associated with a full moon. Whether the settlement is episodic or the movement of the stage back into the Bay is episodic leading to pulses of settlement is not clear. See Figure 7 from McConnaugha for a schematic of crab movements.

3. Sulkin, S. The behavioral basis for blue crab recruitment in Mid-Atlantic Estuaries. Ech. Rept. Maryland Sea Grant UM-SG-TS-81-07

Summarizes past work on the crab:
Larval stages remain near the surface
Likely to be swept out of the Bay into shelf waters
Return flow at bottom may bring them back in to the estuaries

Some work in Texas found that the female crabs will leave Galveston Bay to spawn if the salinity is below 20 PPT.

Lab work shows that early larval stage crabs tend to swim up (negative geotaxis) toward the light (positive phototaxis) and their swimming rate increase with increasing water pressure and with increasing salinity. They work to maintain their presence in the surface waters-bright light and lower salinity.

The negative geotaxis begins to shift to positive by the 4th larval stage and by the 7th stage they exhibit positive geotaxis. They work to move into deeper water near the bottom.

The lab work is generally confirmed by field collection.

4. Sulkin, S., A. Provenzano and C. Epifanio The blue crab in mid-Atlantic Bight Estuaries: A Proposed Recruitment Model. UM-SG-TS 84-02

This report fleshes out the movement of crab larvae and megalopae as described above. It describes a southward outflow from the Bay at the surface that carries the larvae out onto the shallow inner shelf. The surface currents here are affected by southwest prevailing summer winds and carry the larvae to the northeast. As they mature and settle, prevailing landward bottom currents bring them back to the estuaries.

The vagaries of wind direction, speed and duration as well as the occurrence of landward bottom currents are suggested as possible determinants of the recruitments variation each year.

This model raises interesting questions regarding the blue crab cycle in the south shore Great Ponds where there is no continuously open inlet. Depending on the salinity in the ponds, egg hatch in the ponds seems unlikely but may occur either during a spring or summer inlet or in the offshore waters just after a spring or summer inlet in order to satisfy the need for water with a salinity of greater than 20 ppt. The question then becomes how do the post-larval crabs re-enter the ponds? If there is a late spring, late summer or fall inlet, that would provide the mechanism but if there is none or it is a short-lived inlet, there could be very little recruitment that year. Another question is what happens when there is no inlet during the time when the female would normally lay her eggs? She can retain the sperm for a year and delay the egg production. The access question may be a component of the variable crab population in the pond.

5. Blanton, J. et al () The August 1993 North Edisto Ingress Experiment Marine Tech. Rept. 97-01. U. Georgia School of Marine Programs.

Reports on field sampling that demonstrates that on-shore winds are important to delivering crabs to the estuary.

6. Miller, T. (2001) Modeling crab population dynamics. Estuaries 24(4): 535-544

BC is a dominant Benthic predator & scavenger
BC is food for fish scianidae & moronidae (striper)
BC has high fecundity
Some researchers suggest striper predation may be responsible for crab decline
E.g. Baird & Ulanowicz (89)
Stage based model has flexibility. It is heuristic, discrete, time invariant, probabilistic that resemble life tables analysis. Each life stage is longer than model time step and an organism may remain in a stage for multiple time steps
BC mortality rate= based on max. BC life of 8 yrs. based on tag returns; rate = 0.375
BC fishery mort. = 0.88 but varies from 0.62 to 1.26
Fishery impact found to be small but population does vary with the effort in the winter fishery i.e. as fishery declined to 0 in model, projected values of rate of increase increased by 75% but were still negative (from -0.29 to -0.07

Findings:

Blue crab pop able to withstand moderate levels of exploitation with sustainability
Sustainability depends on the balance between natural and fishery mortality
Increases in sustainability proportional with reduction in fishery mortality.
Increasing sea grass also leads to increase in sustainability.
Decrease in summer fishery has more positive effect on sustainability. Than changes in winter fishery
Lack of knowledge about survival of individuals from zoeae to settlement.

7. Goodrich, Montfrans & Orth (1989) Blue crab megalopal influx to Chesapeake Bay: evidence for wind-driven mechanism. Estuarine Coastal and Shelf Science 29: 247-260

Surface flow from bay is seaward. Megalopae must either drop to the bottom to get into density driven inflow or find another way back into the Bay.

Suggest episodic wind driven exchange.
Collection of megs in York river was characterized by pulses separated by time with none/few caught. Average of 10 major inflow events/yr. found by analyzing 28 years of sub tidal volume data.
There is evidence for synchronous night hatch on ebb tide. There is a peak in stage 1 larvae offshore in July – mid-Aug.; from Aug. thru Dec. both meg. and early juveniles found in Bay w/ juveniles in sea grass beds (both Zostera and Ruppia).
Megs capable of vertical movement but don't swim well against horizontal currents
How do they enter the Bay in late summer/early fall???
Found 89% of megs in upper 3 meters (previous work by Johnson 1985).
Another scenario as meg approach metamorphosis, they move to deep water and, during flood tides, ride the current in (Sulkin & Epifanio 1986).

Sampled weekly from mouth of York River from 1985-87 from mid-Aug thru Nov. Frequency allowed resolution of wind driven effects on megs. Also used tide data; Bay sea level changes varying over more than a tide and water flux information. Vol. flux gives better indication of currents than actual field current meter data
Assessed meg settlement on six surfaces sampled daily. Surfaces maintained at 10 to 15 cm below surface takes advantage of natural tendency to cling to surface as they encounter—thigmotaxis.
Assume that number of meg stage animals collected relates to # in water column but ability to cling may vary w/ meg. Competence.
Got spikey, episodic collection—storm surge with hurricane Juan gave largest spike on 1 Nov. '85.
Screened to identify 16 pulses of which 12 were associated w/ + volume fluxes association significance at 95 % level—good correlation.
Frequency distribution of meg data by spectral analysis found a broad peak at 28 days. Possibility of transport or behavior process related to lunar period.
Increases of sub tidal volume greater than one tidal prism defined as inflow events. These events average 9.9/yr over 28 years. At least 6 each year most occur in last 14 days of Sept. associated with storms that were known to break up stratification in Bay. The wind driven timing coincides with time when significant #s of megs found offshore.
They suspect that some megalopae use bottom inflow to get into Bay but this is not prime m. o. for entry into the Bay.
High water during inflow event brings megalopae into sea grasses where thigmotaxis causes them to cling so that they are not removed when the return flow occurs.

8. **R. Lipcius & W. van Engel (1990) Blue Crab Population Dynamics in Chesapeake Bay: Variation in Abundance (York River 1972-1988) and Stock Recruitment Functions. Bull. Marine Science 46(1): 180-194**

The flux in abundance found to stay consistently high numbers or low for 2 years or more and then changed—suggests internal population feedback mechanisms like cannibalism or climatic changes.
The abundance peaked most often in June at 2 stations in York river.
Data from trawl catch and dredge fishery analyzed show significant yr. to yr. , seasonal and spatial variation—effects were only detectable with a 10 to 15 year record.

9. **Noga, E., T. Sawyer, M. Rodon-Veira (1998) Disease processes and health assessment in blue crab fishery management. Jour. Shell. Res 17(#2) 567-577**

Up to 86% mortality from Paramoeba perniciosa
Up to 50% from vibrio parahaemolyticus

Viruses

stress related Herpes virus new family probably in ~ 13% of wild crabs
Baculoviridae
Rhabdoviridae widely found in wild but asymptomatic
Reoviridae lethal in exp. Infected crabs " "
Picronaviridae

They expect predators may remove crabs in wild with viruses and that is why large numbers that are symptomatic are not found.

Bacteria:

mostly vibrios
Not linked to morbidity or mortality in the wild.
Shell disease looks like a burn spot. If a mild case, lesions removed after molting but can penetrate shell and cause problems.
Stress is important in predisposing BC for disease. Hemolymph counts of bacteria increase about 3X when stressed by bleeding in lab compared to unbled animals.

Fungi

Lagenidium callinectes The zoospores settle on eggs and a germ tube penetrates. The fungus spreads over egg mass but mycelia only penetrate ~3mm and therefore the eggs inside are spared.

Amoebae

Perniciosa called gray crab. The hemolymph fails to clot but not apparent until terminal stages probably missed in wild.
Ciliates & peritrichs (lagenophrys callinectes) and suctorians (epibionts on gills)
Both reported on crab gills
Not much documentation of disease or mortality but some evidence of moribund crabs with them.
Frequent molting gets rid of a lot of epibionts.

Microsporidia

Probably only a problem when crabs are stressed.

Haplosporidia

Infections are rare. Probably weakened crabs are predated and not found in wild

Dinoflagellates

Hematodinium perezi found in hemolymph (slow to clot).
Up to 30% presence in crabs from mid-Atlantic.
Gymnodinium breve and Pfisteria piscicida have caused acute kills of crabs and may also non-lethally stress them.

Digeneans and nematodes

In muscle of crabs cause pepper spot.

Nemerteans

Flat or ribbon worms Rhynchocoela.
Carcinonemertes carcinophila parasitizes gills and egg masses.
Very common. It hatches and feeds on eggs but with such large # of eggs BC produce successful spawns despite the prevalence of this.

Barnacles & leeches

Chelonibia patula (acorn barnacle) on carapace
Gooseneck barn (Dichelaspis mulleri) in North Carolina there is 71% infection higher rates on females. (Late stages may not molt like males continue to do).
Heavy infections might inhibit respiration and mobility but still probably not a problem.
Sacculinid barnacle attaches and penetrates the carapace and feeds. Can restrict molting causing button crabs- stunted.

Leech Myzobdella lugubris especially in low Salinity water.

Shell disease

Can be caused by exposure to sewage sludge, pesticides or heavy metals; may be a biomarker for environmental stress.
Considerable mortality-- up to 70% in lobsters w/ it.
Recently an erosive shell disease has been found with up to 25% of carapace may be lost. Mainly in Albemarle-Pamlico estuary but some in Chesapeake.
High density of bacteria found on lesions but also found on normal carapaces- no single bacteria is the dominant one found; can't experimentally reproduce the disease w/out overwhelming bacterial exposure and/or abrading the cuticle.
Possible Causes
Immunosuppression, particularly in low Salinity areas. Possibly associated with biochemical changes in response to this habitat or to pollutants found there.

Possible to use the antibacterial activity of the hemolymph as a biomarker for stress as it may show before clinical evidence of the disease.

10. D. W. Engel & G. W. Thayer (1998) Effects of habitat alteration on blue crabs. Jour. Shell. Res. 17#2 579-586
Chemicals
EPA fish consumption warnings may be an indicator of building problem. Many for NY-NJ area.
Organochlorine pesticides not now used but residues found in sediments.
Today, pesticides are fast acting & gone types ~ organo-phosphorus types are used—
Azinphosmethyl runoff from a large agricultural operation in SC estuary caused significant mortality of juvenile fish and shrimp but no residues found in water w/in 24 hours.
Diflubenzuron mimics arthropod growth hormone and blocks chitin synthesis. This stops molting process and is a threat to juvenile crabs.
Methyl mercury can bioaccumulate. This was shown in Norway lobsters.
Little evidence that significant harm caused by typical environmental concentrations of these materials (organic and inorganic contaminants) – Harm can be shown in the lab.

Eutrophication
Hypoxia
Dinoflagellate blooms
Turbidity threatens eelgrass. There is some correlation between loss of eelgrass and decline of crabs in Chesapeake.
Restored marshes not as highly used as natural even after years in existence.

11. Stehlik L., P. Scarlett & J. Dobarro (98) Status of blue crab fisheries in NJ. Jour. Shell. Res. 17-2: pp. 475-485

Prolonged cold w/ water temp at 0C found to cause substantial kill of young crabs in 1976-77 in Barnegat Bay. These crabs were less than 59mm. In general, blue crabs were scarce following summer.

Occasionally, adults can be winter-killed. There was a substantial kill in 1996 in Delaware and Raritan bays.
Juvenile crabs survive predation better in muddy environments w/ macroalgae than they did with no vegetation.
Recreational fishery
May equal or exceed commercial harvest.
Can use licenses (free) as a way to determine the amount of fishery. The license is only for traps.

12. Briggs, P. (1998) New York's blue crab (Callinectes sapidus) fisheries through the years. Jour. Shell. Res. 17(#2): 475-486
NY= recreational Harvest thought to be substantial

13. Orth, R & J. van Montfrans (2002) Habitat Quality and prey size as determinants of survival of post larval and early juvenile instars of the blue crab C. sapidus. Marine ecology progress series 231: 205-213
Lab simulations
Simulated eelgrass habitat at 500 and 1500 shoots/M^2 and Spartina alterniflora at 97 and 291 shoots/m^2. Then observed fundulus heteroclitus predation on post larvae and first juvenile instar blue crab.

Looked at juvenile crab size effects on survival during fundulus predation.
Mean proportional survival higher for both stages in eelgrass.
No difference in life stage survival in the Spartina.
Increasing proportional survival found with increasing size and no cover.
Megalopae use sea grass habitats.
Later stage juveniles redistribute to different habitats based on size, sex, molt stage, Salinity and food availability.
Sampling shows abundance is higher where there is structured habitat i.e. eelgrass or other vegetation.
Younger, smaller crabs found in eelgrass beds and later stage crabs (11mm to 25mm) found more in marsh channels.

Proportional survival of all stages in the sea grass at both densities was higher than survival in the marsh grass
Prey survival proportional to a quantifiable factor like biomass density or surface area

14. Ryer, C., J. van Montfrans K. Moody (1997) Cannibalism, refugia and molting blue crab. Marine Ecology Progress series 147:77-85

Tethered both soft and hard shell crabs in marsh creek and sea grass beds over low and high tides to determine survival.
Soft crabs were cannibalized by other blue crabs 47 times; no other species preyed on soft crabs.
In august, 95% of hard crabs survived compared to 34% of soft crabs.

While exoskeleton is shed and for a time after, soft crabs are immobile, their chela useless and can't flee or defend. They are vulnerable.
Soft crabs in bags may have inhibited some other predators but no signs seen of any predators other than blue crabs.

15. L. Pihl, S. Baden, R. Diaz (91) Effects of periodic hypoxia on distribution of demersal fish. Marine Biology 108: 349-360

Several species studied migrated out of deeper (over 10m) water during hypoxia and returned after the event ended.
Blue crab survived in 14 to 25% Oxygen saturation.
Hypoxia below 2ppm or 28% sat for 6, 14 and 6 day periods was monitored during summer.
Adult crabs found at all depth ranges sampled in June. First hypoxic event did not change their presence. During second event crab density decreased in sampling sites.
No significant changes in blood haemocyanin found except for deepest sampling zone during and after the second hypoxic event.

16. R. Lipcius, E. Olmi, J. van Montfrans (90) Planktonic availability, molt stage and settlement of blue crab post larvae. Marine Ecology Progress series 58:235-242

Larvae move seaward thru 7-8 stages then metamorphose to megalopae return to bay and are recruited.
Recruitment= immigration of larvae, megalopae or young juveniles into estuarine habitats.
These stages are active swimmers. Settlement not a passive thing.
Enter settlement sites in pulses on flood tides around the new or full moon.
Settlement is governed by their availability in the plankton and by stage readiness to settle.
Developmental stage moves from retention in upper layer at megalopae stage to movement to the bottom for juvenile crabs. They move from negative geotaxis (stay off the bottom), positive phototaxis (move toward light) and high barokinesis (move away from higher water pressure) to reduced locomotory, positive geotaxis, negative phototaxis and thigmotaxis (clinging).

Megalopae don't have to settle—they have some ability for habitat selection before they have to settle. Juveniles do have mobility and can move to a new habitat after settlement.

17. K. Wilson, K. Able K. Heck (90) Predation rates on juvenile blue crabs in estuarine nursery habitats: evidence of importance of macroalgae (Ulva lactucca) Mar Ecol Prog Ser 58: 243-251

Tethering experiments in eelgrass, Ulva, bare and tidal creek compared.
Mean predation rates in sea lettuce =9% in eelgrass = 20% compared to 40% or more in unvegetated sites.
In mid Atlantic state estuaries lacking red drift algae commonly have Ulva on otherwise unvegetated ground.

18. Olmi, E. (1994) Vertical migration of blue crab C sapidus megalopae: implications for transport in estuaries. Marine Ecol Prog Series 113: 39-54

Measured #s of megalopae at 3 to 4 meter depth and 10-meter depth in York river.
Megs found near surface during flood tides at night. Most were in upper 30 cm in October sampling.
Megs were less abundant when the flood tide was during daylight and were found deeper and more spread thru the water column near dusk.
During daylight megs remain near the bottom at 9 to 10 meters but at night most concentrate within 2 meters of surface.
Megalopae distribution suggests that they move from bottom toward surface as darkness comes on.
Found significantly more megalopae in water column during flood than ebb- selective tidal stream transport up the estuary.
Abundance and vertical distribution not related to Temp, Salinity, stratification, current or wind speeds.

20. L. Etherington & D. Eggleston (2000) Large-scale blue crab recruitment: linking post larval transport, post-settlement planktonic dispersal and multiple nursery habitats. Marine Ecology Progress Series 204 179-198

North Carolina Pamlico-Albermarle estuary is primarily a wind driven estuary.
High spatial and temporal variation in settlement was found. Settlement was consistently high in eastern areas nearest to oceanic sources of larvae.
Larval on shelf for 30 days.
Post-larvae move into estuaries then settle and metamorphose into juvenile crabs.
2 seasonal peaks in recruitment were found: May
LARGER PEAK IN Aug/Sept
Density of blue crabs (J1-J2) not related to Submerged Aquatic Vegetation biomass or # shoots but there was a correlation with length of leaves.
Seem to settle into SAV beds and then disperse so that later stages are found throughout the system whereas the J1-J2 are all in sea grasses or other structured habitats in the eastern region. This area has the sea grasses as well as being closest to the shelf waters and the immigrant post-larvae.
Found similar numbers of early stages in Myriophyllum spicatum and in detritus where some structure is provided.

Later stages j5-j3 higher in sea grasses.
Passage of tropical storms may deliver megalopae to other parts (aside from eastern area) of the estuary.

21. Orth & Montfrans (90) Utilization of marsh and sea grass habitats by early stages of C. sapidus: a latitudinal perspective Bull mar sci 46(1) 126-144

Multiple factors affect crab population other than quantity of nursery habitat.
In Gulf area there a good correlation exists but not in Chesapeake Bay.
High abundance in Chesapeake may relate to high delivery rates of megalopae.

Lower abundance of crabs in Delaware Bay attributed to less sea grasses.
Presence or absence of sea grasses probably affects crab pop in Ga. and NC

22. Olmi, E. (1995) Ingress of blue crab megalopae in the York River, VA 1987-1989. Bull. Mar. Sci. 57(3): 753-780

Collected plankton samples nightly during maximum flood.
Local wind forcing and tidal currents were important in moving megs.
The # and timing of wind events may be a very important factor in interannual variation in recruitment.
Megalopae abundance episodic. They found 2 to 8 days of high abundance separated by at least a few days of low abundance. Move in pulses.
In 1987 about 50% of all megs captured occurred during an 8 day period in early Sept.
In 1988, the year of most megs, about 75% caught mid-Aug to late Sept.

Abundance :

- possible correlation of #s with Temp
- Salinity probably a result of wind and tide forcing
- Good correlation with wind stress around date of collection
- Some correlation with tide range (use of flood to migrate)
- E-W wind associated with meg abundance-- west blowing wind correlates with high abundance

23. Natunewicz, C., C. Epifanio & R. Garvine (2001) Transport of crab larval patches in the coastal ocean. Mar. Ecology Progress Series 222: 143-154

Larval clusters about 2 kilometers in diameter were found in the upper 2 meters consisting of 100 to 1000 individuals per cubic meter. These patches were separated by areas with less than 10 individuals. The patches off Delaware Bay were tagged with satellite monitored drifters that were set to keep station with the patches as they drifted for 1 to 11 days. The path of the patches was assessed by measuring salinity, temp. wind and river discharge. South winds pushed the patches in toward the coast. North winds mixed patches offshore out of the outflow plume from the bay.

Patches came out of the bay under the effect of the outflow plume. As river discharge slowed, winds more dominant in deciding the path of the patches. The 7 larval stages require 3 to 6 weeks to complete.

Prepared a 2 dimensional advection-diffusion model to evaluate the factors in movement of the patches. Found that tidal circulation had little effect on the long-term larval movement. The tides were found to cause some diffusion of larval patches.

APPENDIX C

BLUE CRAB POPULATION INFORMATION

Anecdotal information on blue crab populations:

Conversation with Tom Hodgson, 26 February 2004:

Tom reports very few crabs in August 2003. After about 3 hours of crabbing he only had 6 to 8 crabs. This was very poor compared to previous years.
He remembers the last "good" year being about 4 to 5 years ago.
He has seen females bearing eggs in the pond.
He recalls Chilmark Pond having a large population about 4 to 6 years ago. There was a large number there waiting for the summer opening that year. He could dip up about 6 with each swipe of the crab net.

Paul Bagnall, Edgartown Shellfish Warden and Biologist, 27 February 2004

The last few years have been very poor for crabs in both Oyster and Edgartown Great Pond.
Paul believes that the populations in the south shore pond don't always cycle up and down together.
When it is a good year, there are huge numbers and crabbers could fill trash barrels with them if they wanted.
Paul has seen egg-bearing females in the Pond. Not too often but occasionally.
No one catches them commercially. The license is the same as a lobstering license and lobsters are far more lucrative.

Ray Houle, West Tisbury Shellfish Warden, 27 February 2004

Ray feels the crab population is periodic— a couple of good years followed by some years with fewer.
He has seen females with eggs along the barrier beach but doesn't recall seeing too many males there.
When there are large numbers they are often in the creek connecting to Black Point Pond or along the barrier beach.

Peter Huntington, 2 March 2004

Peter agrees that the last good year in Tisbury Great Pond was 4 to 5 years ago. He recollects it was the year that there was no summer opening. It may have followed the year with a drowning in the inlet. There were so many that he saw crabs swimming out in the middle of the pond. The pond was very turbid at that time. **Note**: That appears to be 1999 from Kent Healy's pond level data. The pond closed May 24 and didn't open until mid-September around the time of hurricane Floyd.
He says the crab population is not necessarily synchronous in Tisbury Great and Chilmark Pond.
He thought the population had a large percentage of female crabs in 2003. They were hugging the barrier beach and may have gone over the beach on a tide surge.
As a child he remembers the crab populations being more uniform from year to year at higher numbers.
The crabs gathering at the barrier beach usually peak in August.

Gus Ben David, 28 April 2004

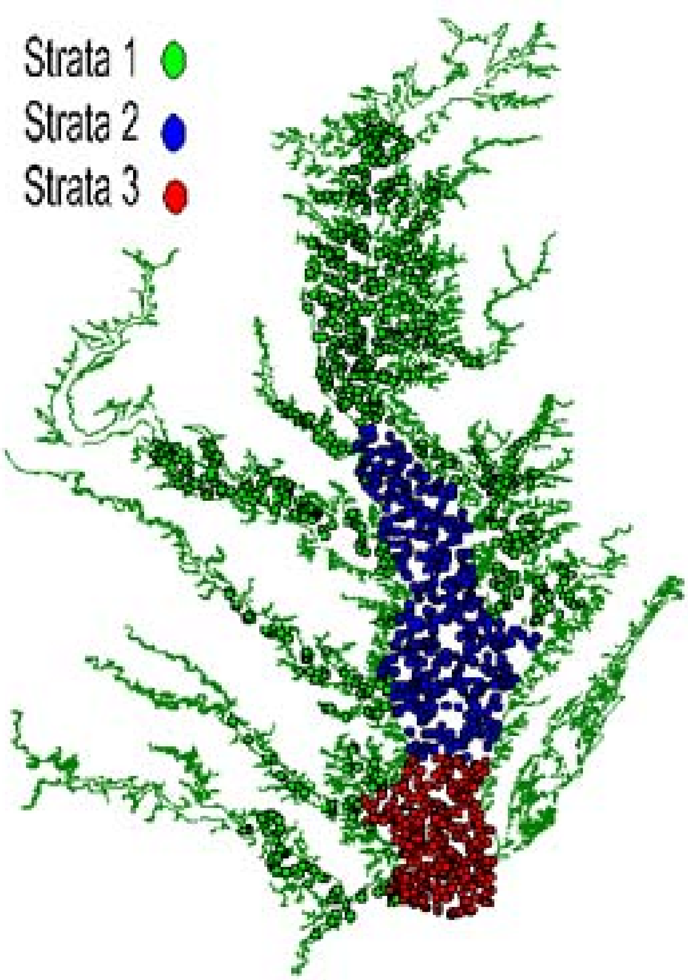
Gus believes that there are some adult crabs that enter the pond(s) from off shore. George Flynn reported these to him from observations in Edgartown Great Pond. Gus indicated that they are large male crabs (primarily) that show up with clean shells that are not fouled by algae.

BAY-WIDE BLUE CRAB

WINTER DREDGE SURVEY

2003

INTRODUCTION: The winter dredge survey is the only Bay-wide fishery-independent effort to assess status of the blue crab population in the Chesapeake Bay. The dredge survey produces estimates of abundance, indices of recruitment, indices of female spawning potential, and estimates of relative exploitation of the blue crab by commercial and recreational fisheries. A pilot version of the study was first conducted in 1988 with the cooperation of the University of Maryland Chesapeake Biological Lab (CBL). In 1989 the Virginia Institute of Marine Science (VIMS) joined the survey, and the two states continue to sample each winter from December through March.



SAMPLING AREA AND INTENSIT the survey has been conducted according t random design (*Rothschild and Sharov, 19* divided into three strata: Lower Bay (the m Chesapeake to Wolf Trap Light, Middle B Light to Cove Point) and the Upper Bay/T Point to Pooles Island and all of the Bay's total of 1500 sites in waters deeper than 1. randomly selected each year. The number per stratum is proportional to the area of th addition to the comprehensive coverage of stratified random sampling, 125 fixed sites by MDNR and VIMS as part of the survey

SAMPLING PROTOCOL: A 1.83 m wide Virginia crab dredge fitted with a 1.3 cm (0.5 in) nylo towed along the bottom for one minute at a speed of three knots. Latitude and longitude, measured w Global Positioning System (GPS) are recorded at the beginning and end of each tow to determine dist Distance is multiplied by the dredge's width to calculate the area covered. Beginning and ending dep temperature, and salinity are recorded at each site. Blue crab carapace width (CW) and weight are me nearest millimeter and gram). Sex is determined and maturity of females is noted.

Each year gear efficiency is estimated by dredging repeatedly in areas of medium or high crab density experiment consists of six coverages of a 100m X 5.5m (three dredge-width) area. One coverage is co adjacent, non-overlapping tows within the experiment area. The decline of crabs in each consecutive us to estimate the efficiency of the dredge and to correct the final estimates of abundance accordingly information see: *Volstad et al. 2000 and Sharov et al. 2001*.

RESULTS

Age Determination	Mean Crab Density	Relative Abundance
Blue Crab Size	Relative Exploitation Rates	Absolute Abundance

AGE DETERMINATION:

The blue crab population is made up of predominantly three age classes; age 0, age 1, age 2+. The age classes are separated by their carapace width or maturity as listed below. This allows us to analyze density of crabs that were entering two important fisheries, peelers (age 1) and hard crabs (age 2).

Code	Maturity Level	Size Criteria
(M0)	Age 0 Males	Males < 60mm CW
(F0)	Age 0 Females	Females < 60mm CW
(M1)	Size 1 Males	Males 60-119mm CW
(F1)	Size 1 Females	Immature females ≥ 60mm CW
(M2)	Size 2 Males	Males 120mm ≥ CW
(F2)	Mature Females	Mature Females
(M1+)	Age 1+ Males	Males ≥ 60mm CW
(F1+)	Age 1+ Females	Females ≥ 60mm CW
(T0)	All age 0	M0 + F0
(T1)	All size 1	M1 + F1
(T2)	All size 2 Males Mature Females	M2 + F2
(T1+)	All age 1+	1 + F1 + M2 + F2

MEAN CRAB DENSITY:

Mean crab density (D) is calculated with the following equation, where D is measured in units of crabs per $1000m^2$ (*Cochran, 1977*). The equation is used to determine the amount of crabs that are in each of the three strata.

$$D = \sum (a_h/a_t (\sum(c_i/a_i)_h/n_h)) \times 1000$$

Where:

a_h = area, in km^2, of stratum h,

a_t = total area of all strata combined,

a_i = area covered by dredge tow I,

c_i = number of crabs captured in dredge tow I,

and

n_h = number of dredge towns in stratum h.

Total mean crab densities are calculated for every year of the winter dredge survey. The table below presents total crab densities for years 1990 to 2003. Use the "Code" abbreviations listed in the table in ***Age Determination*** as a key for the age of the blue crabs in the mean crab density table below (T = Total Crabs/all age classes). The mean crab density is measured in the number of crabs per $1000m^2$, so the mean abundance of total crabs (T) in 1990 is 82.16 crabs per $1000m^{2.}$

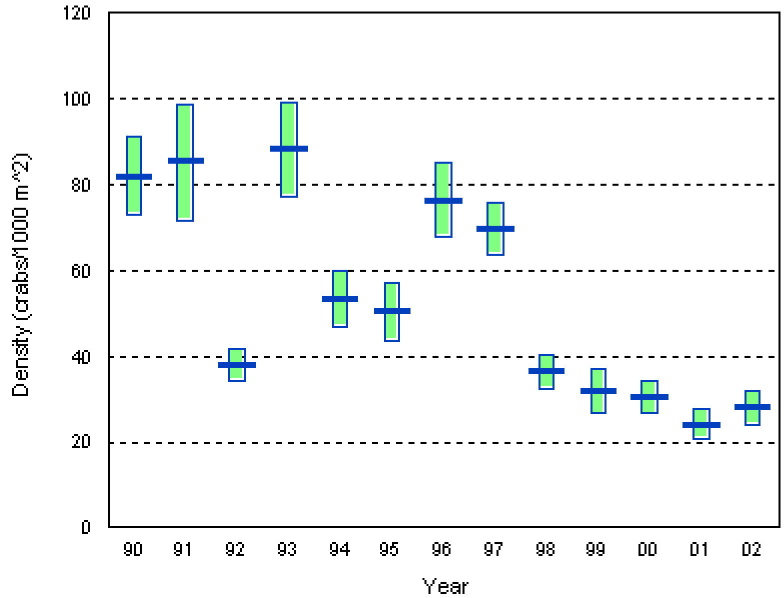
Bay-Wide mean blue crab densities for each age category

Year	T	T0	T1	T1+	T2	M0	F0	M1	F1	M2	F2
1990	82.16	47.34	16.97	34.82	17.85	26.53	21.99	11.69	5.89	8.84	9.01
1991	85.53	36.43	18.38	49.11	30.73	20.13	19.41	13.61	6.04	12.14	18.59
1992	38.14	10.69	7.06	27.44	20.38	4.98	5.54	4.34	2.73	4.86	15.52
1993	88.32	51.27	24.63	37.05	12.42	25.03	25.05	11.95	8.56	6.21	6.21
1994	53.55	30.94	8.77	22.61	13.84	15.38	15.83	6.08	2.85	4.56	9.28
1995	50.43	30.71	11.35	19.72	8.37	13.13	15.37	6.24	3.75	4.01	4.36
1996	76.50	51.82	9.31	24.68	15.37	25.37	26.53	5.60	3.71	5.30	10.07
1997	69.76	52.16	6.71	17.59	10.88	24.01	27.97	3.95	2.73	3.40	7.48
1998	36.43	16.87	7.38	19.54	12.16	7.54	9.34	4.40	2.98	3.89	8.27
1999	31.93	22.76	2.43	9.17	6.74	9.58	13.19	1.21	1.21	2.01	4.73
2000	30.49	13.90	3.77	16.59	12.82	6.45	7.44	2.31	1.47	2.11	10.71
2001	26.64	15.86	4.11	10.76	5.70	7.05	7.40	2.65	1.96	1.93	4.24
2002	32.35	19.81	3.68	12.54	7.29	7.25	9.79	2.85	1.47	3.82	4.40
2003	39.80	17.88	9.32	21.91	12.59	9.53	8.35	5.97	3.35	7.90	7.69

RELATIVE ABUNDANCE:

All age classes: Relative abundance has been increasing since 2001, but remains well below abundance totals seen prior to 1998 (Figure 1). When regressed against commercial landing data, density shows a significant, positive relationship with amount landed (Figure 2).

Figure 1: Density of blue crabs estimated from the Chesapeake Bay winter dredge survey, 1990-2003, with 95% confidence intervals.



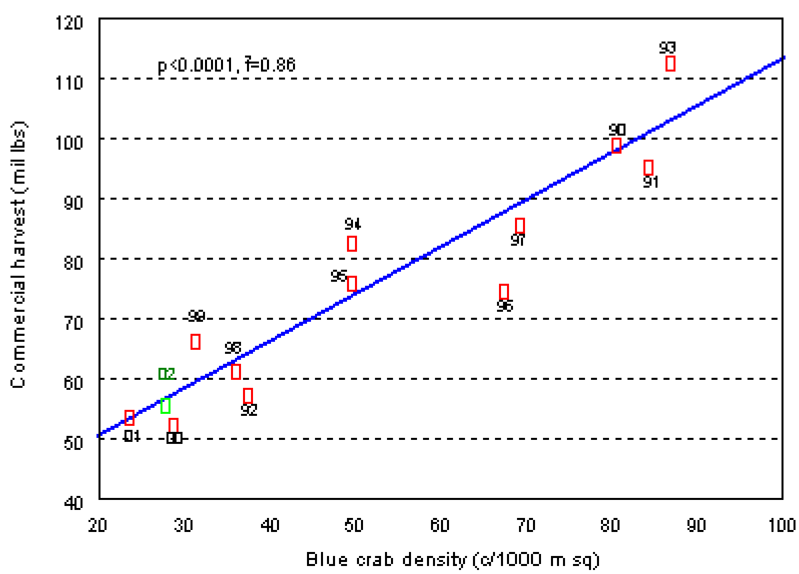
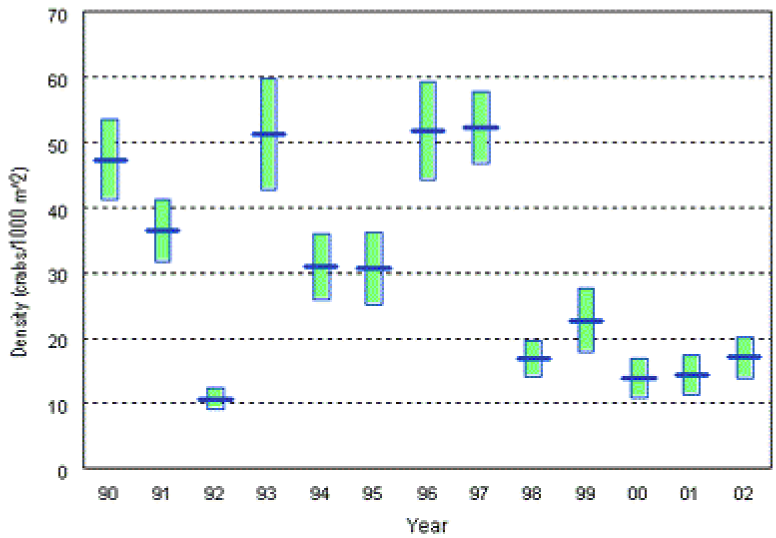


Figure 2: Linear Relationship of estimated over-wintering blue crab density and Bay-wide commercial harvest. Each block represents a year.

Age 0 and Age 1+: Age 0 crab densities have shown no trend from 1998 to present (Figure 3). Recruitment was relatively high prior to 1998 with the exception of poor recruitment in 1992. Since 1998 recruitment has shown no significant variation and has been poor. For the first time since 1993 the 2003 relative abundance of Age 1+ male and female crabs increased significantly, marking the first upswing in a trend that has been steadily declining since 1993. Age 1+ female densities have fluctuated without trends. The 2003 density estimate is significantly higher then the 2002 estimate, the second lowest annual estimate in the survey (Figure 5). Density of adult males (>120mm CW) has declined over time. The 2003 estimate is higher then the estimate reported in 2002 (Figure 6).

Figure 3: Density of age 0 blue crab (<60mm CW) estimated from the Chesapeake Bay winter dredge survey, 1990-2003, with 95% confidence intervals



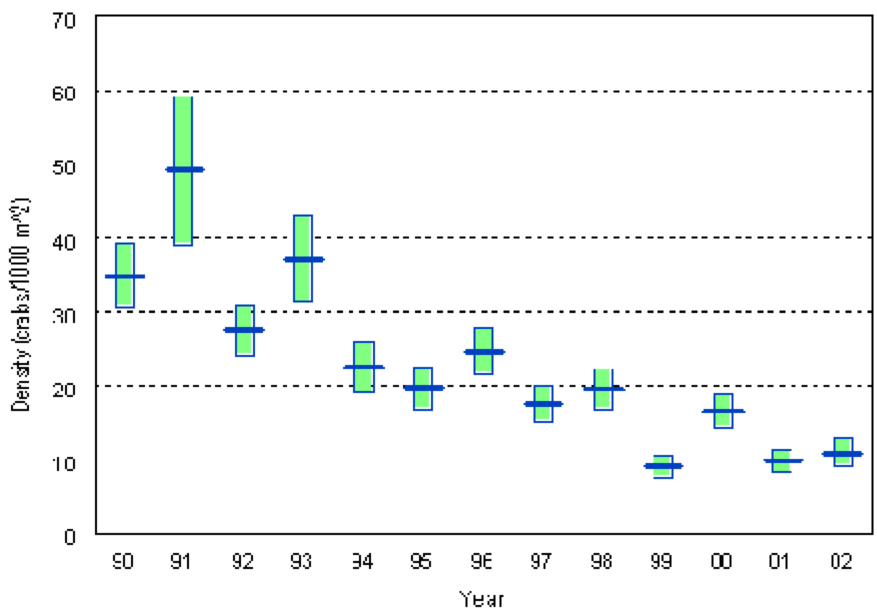


Figure 4: Density of age 1+ blue crabs (immature females 60+ mm CW and males 60-120 mm CW) estimated from the Chesapeake Bay winter dredge survey 1990-2003, with 95% confidence intervals

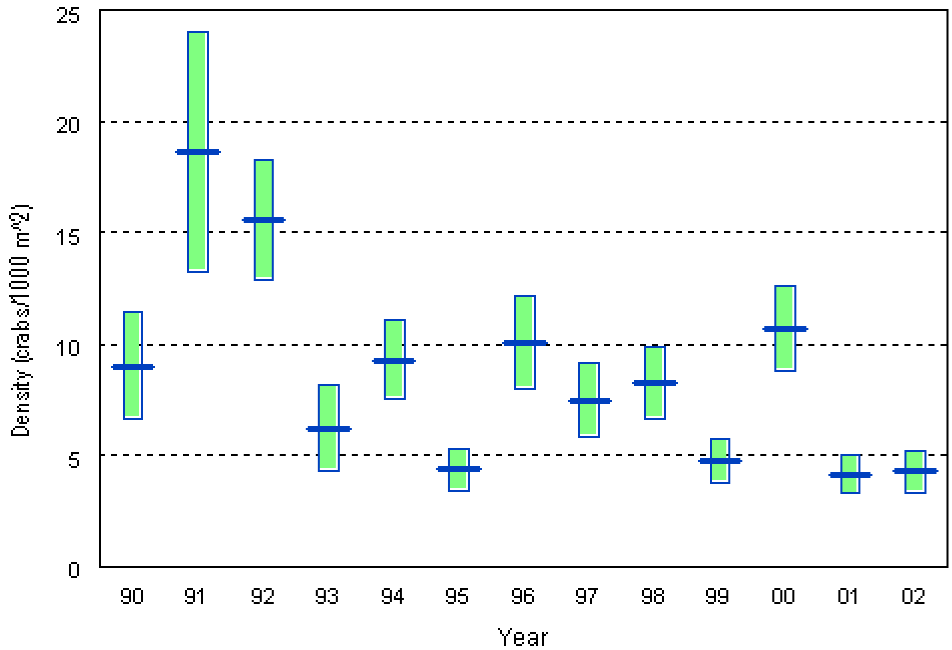


Figure 5: Density of mature female blue crabs estimated from the Chesapeake Bay winter dredge survey, 1990-2003, with 95% confidence intervals

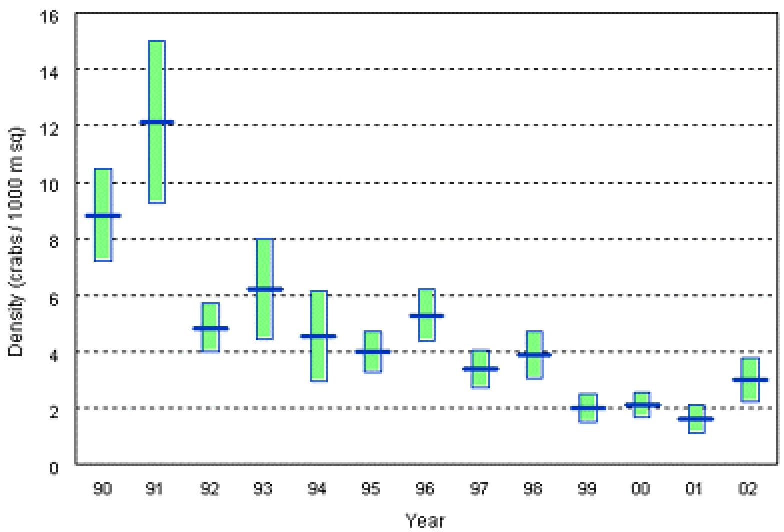
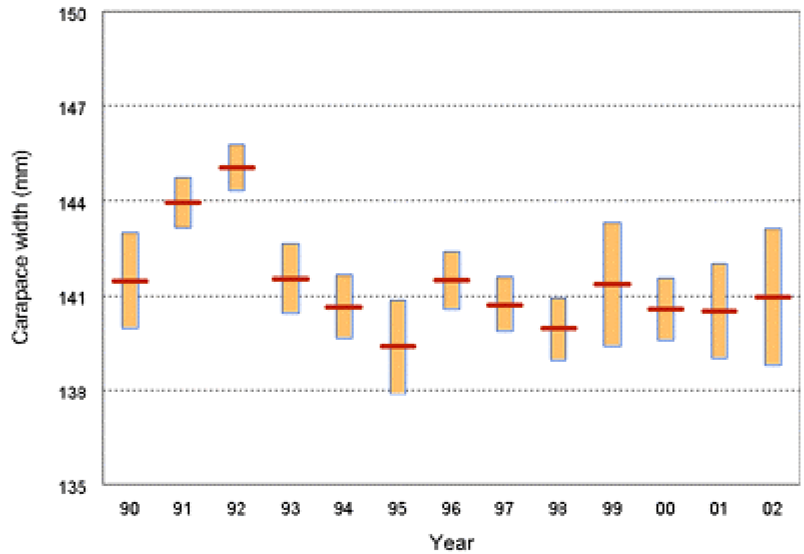


Figure 6: Density of mature males (≥ 120mm CW) blue crabs, adjusted for catchability, estimated from the Chesapeake Bay winter dredge survey, 1990-2003 with 95% confidence intervals.

BLUE CRAB SIZE:

The mean size of exploitable hard crabs (mature females, legal males = males > 127mm CW) had not shown any trends or significant fluctuations over the duration of the study. Mean size of males in 2003 is significantly lower then the record high in 2002 (Figure 7 and 8).

Figure 7: Mean carapace width of mature female blue crabs captured in the Bay-wide winter dredge survey, with 95% confidence intervals.



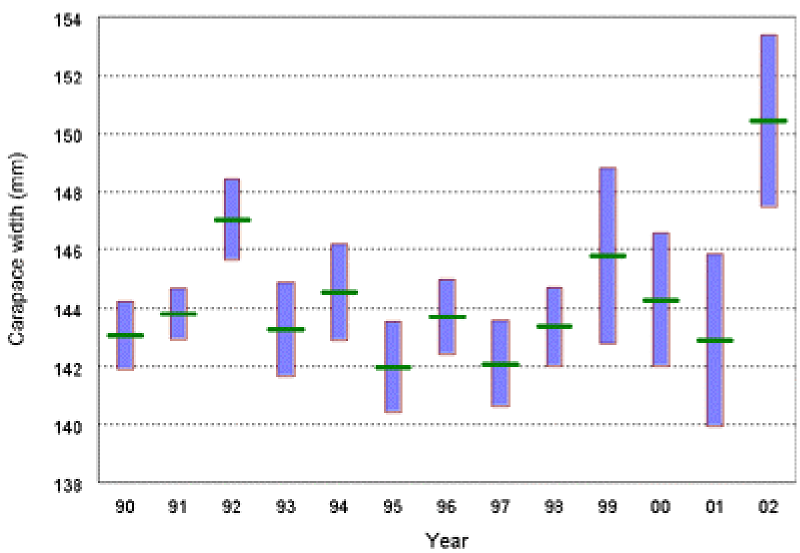


Figure 8: Mean carapace width of legal male blue crabs (+127mm CW) captured in the Bay-wide winter dredge survey with 95% confidence intervals.

RELATIVE EXPLOITATION RATES:

Relative exploitation rates are an estimate of the number of crabs being removed from the population by harvesting. Relative exploitation rates have almost doubled since 1990. There has been a statistically significant increase in the exploitation rates over the time series (Figure 9).

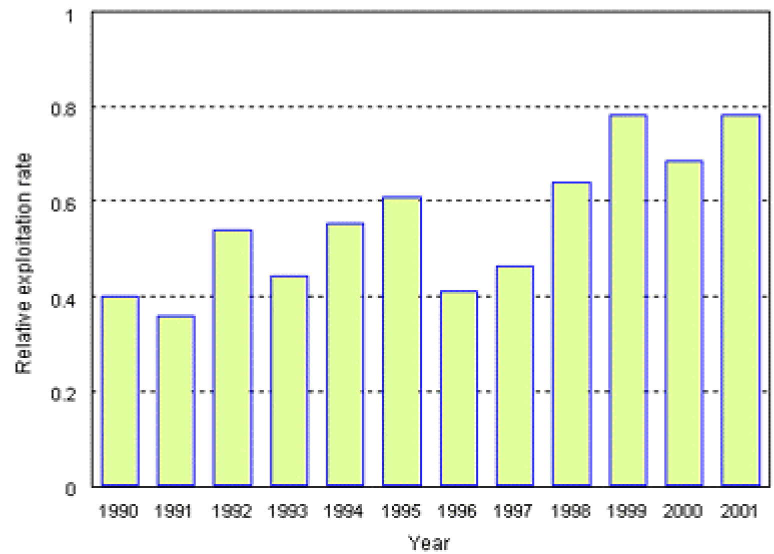


Figure 9: Estimates of relative exploitation rate, based on reported harvest and on the Bay-wide winter dredge survey population estimates.

ESTIMATED ABSOLUTE ABUNDANCE:

Estimated absolute abundance is the estimate of how many blue crabs are over-wintering in the Chesapeake Bay. The number is based on the density of crabs (crabs/m^2) but multiplied over the entire sample area (9814.57 km^2). The estimated for each year are listed in Table 5:

Table 5. Annual estimates of over-wintering abundance (in numbers) of blue crabs in Chesapeake Bay, 1990 – 2002.

Year	Abundance
1990	806,365,071
1991	839,440,172
1992	374,327,700
1993	866,822,822
1994	525,570,224
1995	494,948,765
1996	750,814,605
1997	684,664,403
1998	357,446,639
1999	313,379,220
2000	299,246,239
2001	261,460,145
2002	317,501,340
2003	390,619,886

References:

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• Rothschild, B.J. and A.F. Sharov. 1996. Abundance estimation and population dynamics of the blue crab in the Chesapeake Bay: final report to NOAA Chesapeake Bay stock assessment committee. UMCEES [CBL] 95-207.

• Sharov, A.F., J.H.Volstad, G.R.Davis, B.K. Davis, R.N. Lipcius and M. Montane. In press. Abundance and exploitation rate of the blue crab (*Callinectes sapidus*) in Chesapeake Bay. Bull. Mar. Sci.

Glossary:

Carapace width: The width of the crab measured from point to point.

Recruit: In this case, newly settled juvenile crabs, but also refers to crabs that have moved into a certain size or age class. Male crabs recruit to the fishery at 5.25 inches.

Recruitment: A measure of the number of crabs that enter the population within the year. Also a measure of the number of crabs that grow to harvestable size within the year.

Relative exploitation: An index of the fraction of crabs removed by harvest over time.

Spawning potential: The number of eggs that could be produced by an average recruit.

Stratified random design: An experimental design that separates the bay into three geographic areas (strata), choosing a number of random sites, proportional to the area of the strata.

Virginia Crab Dredge: A dredge consisting of a metal frame with a bag net made of iron rings, s-hooks, or nylon netting. The leading edge of the device is a heavy iron bar with 5-7 inch teeth. Comes in a variety of sizes and dimensions but is typically 6-8 feet wide and weighs around 250 pounds.

VIRGINIA INSTITUTE OF MARINE SCIENCE

TRAWL SURVEY DATA

The primary goal of the survey is to develop "indices of abundance" for a number of juvenile recreationally, commercially, and otherwise ecologically important species. These indices measure the relative size of each "year class" for the target species. Calculation of the index is basically an average catch-per-tow computation, after the data are statistically treated to minimize the effect of extremely high and low catches.

How to create an index of abundance.

Most species targeted by this survey are available to the survey nets for a limited amount of time during the year, because of seasonal abundance and migrations out of the Bay. Further, many species have a limited geographic range within the Bay and its tributaries. For each species then, only three or four months of highest abundance are used in computation of the index; and only the areas in which each species is most plentiful are included for the index. For some species this is all river and Bay segments, for others only the Bay or subsections of the Bay are used, and for still others only the rivers or river segments are used.

For most target species, individuals become susceptible to, or can be caught by, the survey nets several months after hatching, when they are referred to as Age 0 (young-of-the-year) or "juvenile" fish. Some species are also (or exclusively) caught as older individuals. For some species, this group of older fish is only one year class and for other species it is several. Indices are also calculated for these older groups. Where these indices clearly represent only one year class, they are labeled as "age 1"; where they include several year classes, they are referred to as "Age 1+".

So, what is so important about juvenile indices?

Juvenile indices serve several purposes. Most importantly, they serve as an annual indication of recruitment success or failure, for example, providing an "early warning" of year class failure. They allow us to monitor the pulse of the Bay. These indices can also be an indication of the success or failure of a management plan or regime, and serve as the data for input to stock assessment models used by the managers. In addition, the length of the time series allows an analysis of the possible causes driving year class success or failure, and allows us to see long-term changes in populations that may be caused by over-harvesting, pollutants, or climate change. Finally, the data provide a valuable information base for student research on age and growth, pollutant body burdens, climate interactions, stock identification, and population dynamics of the various species.

Indeed, the VIMS Trawl Survey is just one element of a VIMS comprehensive fish monitoring program which includes beach seine surveys targeting striped bass, white perch, and bluefish; surveys which sample juvenile shad much farther upriver than the Trawl Survey; and pound net and gill net surveys which sample adult fish of several species. Because most of these species are migratory, the VIMS surveys are elements of multi-state monitoring efforts that support interstate fishery management plans. When combined with other surveys that sample fish, a comprehensive picture of the relative condition of a fish population can be compiled.

Several Maryland-Virginia bistate fishery management plans call for a continuation of the VIMS trawl survey to make annual estimations of recruitment success. Further, Atlantic States Marine Fisheries Commission and Mid-Atlantic Fisheries Management Council interstate and regional fishery management plans cite the need for monitoring and support for annual recruitment of juvenile finfishes. The trawl survey and seine surveys provide these data.

How to create a juvenile index

The primary goal of the survey is to develop estimates of juvenile abundance for important species in the Chesapeake Bay. Estimating catches of juveniles (usually individuals born during the present year) helps evaluate the health of a stock, and allows possible forecasting of future commercial and recreational abundance. For a given species, an index is created by selecting both spatial and temporal components. The spatial component is determined by the range of the animal and catch rates across the sampling area. The temporal component is selected as a three to four month window when the species is most fully recruited to the estuary and available to the sampling gear. With both the spatial and temporal components selected, the data are statistically treated to produce a "weighted geometric mean catch per trawl", or more simply put, an average catch rate. These values are only relative to similar data in the past. However, with several years of data (i.e. the VIMS Trawl Survey), the results can provide a very informative picture of the species' health and spawning success in the Chesapeake Bay.

The attached graphs give survey results for the past 15 years for 19 species. Data for the years prior to 1979 are not presented because we are currently evaluating conversion factors to standardize the various gear modifications.

The horizontal axis for each graph represents the "year class" year for that species. For some species, we measure year class strength in the calendar year following the year of hatching; therefore, there is no 1994 data for those species.

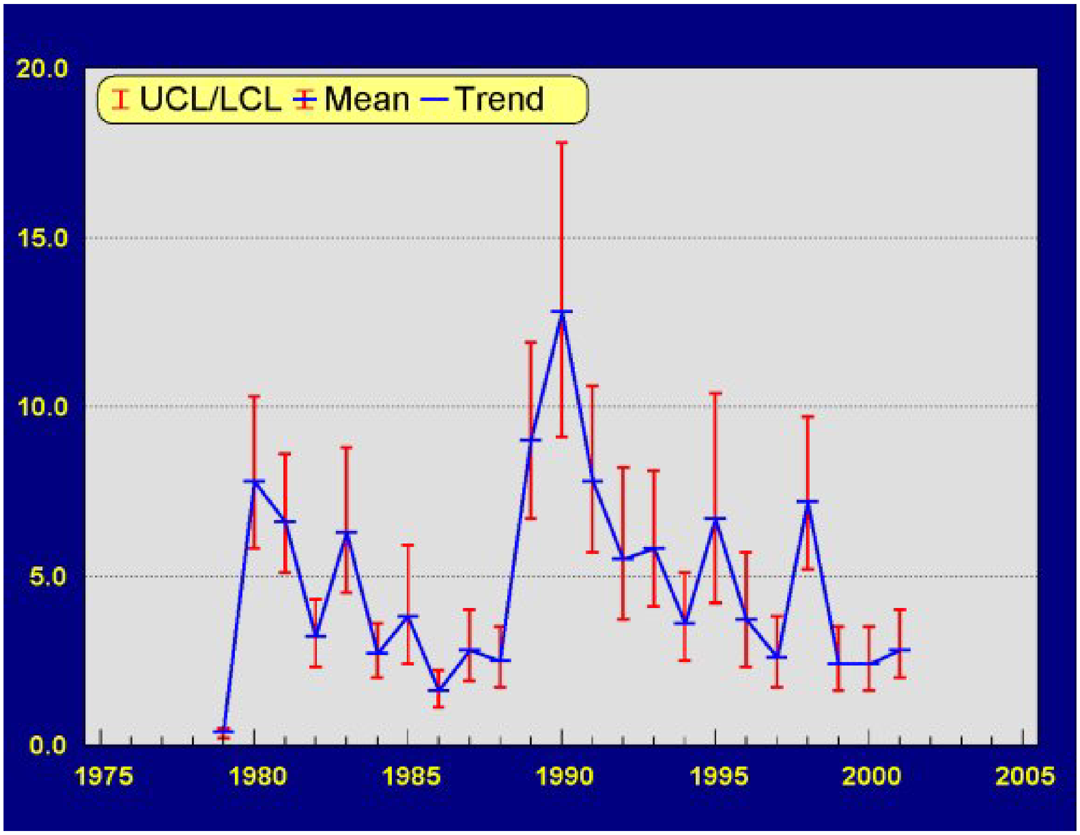
Indices for Atlantic croaker (*Micropogonias undulatus*), striped bass (*Morone saxatilis*), alewife (*Alosa pseudoharengus*), and American shad (*Alosa sapidissima*) are based on only river samples and are presented for only one year class. Computations for windowpane (*Scophthalmus aquosus*), smallmouth flounder (*Etropus microstomus*), striped anchovy (*Anchoa hepsetus*), Atlantic silverside (*Menidia menidia*), scup (*Stenotomus chrysops*), butterfish (*Peprilus triacanthus*), harvestfish (*Peprilus alepidotus*), northern puffer (*Sphoeroides maculatus*), inshore lizardfish (*Synodus foetens*), and northern searobin (*Prionotus carolinus*) are based on only Chesapeake Bay samples so only one index is presented and with data only from 1988 to the present.

For some species more than one index is shown. There are three situations where this occurs:

- For spot (*Leiostomus xanthurus*), weakfish (*Cynoscion regalis*), silver perch (*Bairdiella chrysoura*), summer flounder or fluke (*Paralichthys dentatus*), bay anchovy (*Anchoa mitchilli*), spotted hake (*Urophycis regia*), and black seabass (*Centropristis striata*), the most reliable index is based on both Chesapeake Bay and river samples. However, since the Bay stations have only been regularly sampled under the present format since 1988, a "Rivers Only" index is also presented in order to give the longest possible view of the data.
- For Blackcheek tonguefish (*Symphurus plagiusa*), hogchoker (*Trinectes maculatus*), channel catfish (*Ictalurus punctatus*), white catfish (*Ictalurus catus*), blue catfish (*Ictalurus furcatus*), and white perch (*Morone americana*), both Age 0 and Age 1 (+) indices are shown.
- For blue crabs (*Callinectes sapidus*), both an index for "juvenile" (up to about 65mm or 2 1/2") crabs which will enter the fishery several months later, and one for "recruits" (those either just under or already at legal size) are presented.

The methods used to calculate indices of abundance from the VIMS Trawl Survey data sets are constantly under review. The "cut-off lengths" used to separate young-of-year (YOY) from older fish, along with the geographic and temporal data limits used for each species, may change as more study is done.

Blue Crab Age 0-Fall index

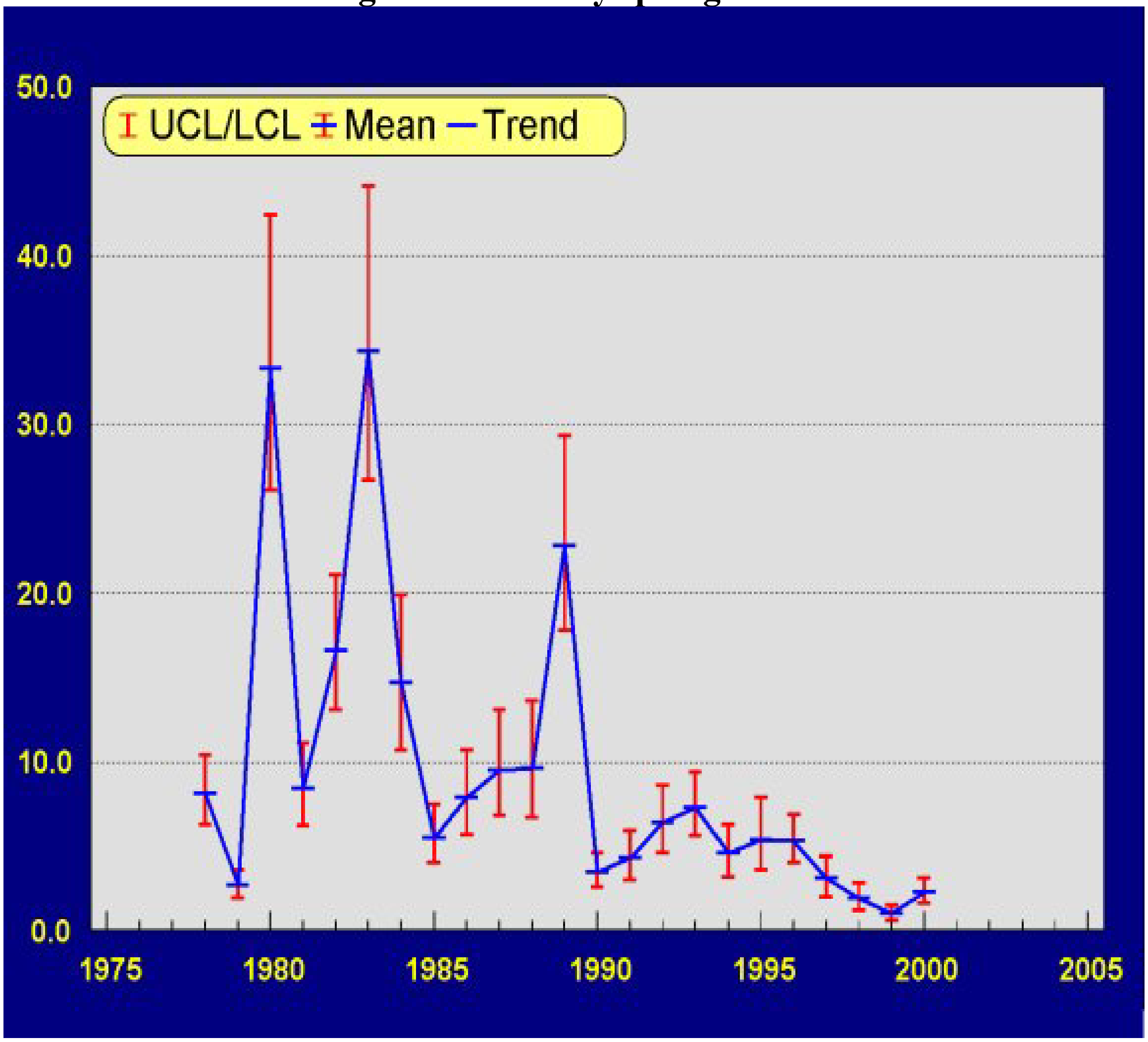


<u>Key for this and following charts</u>

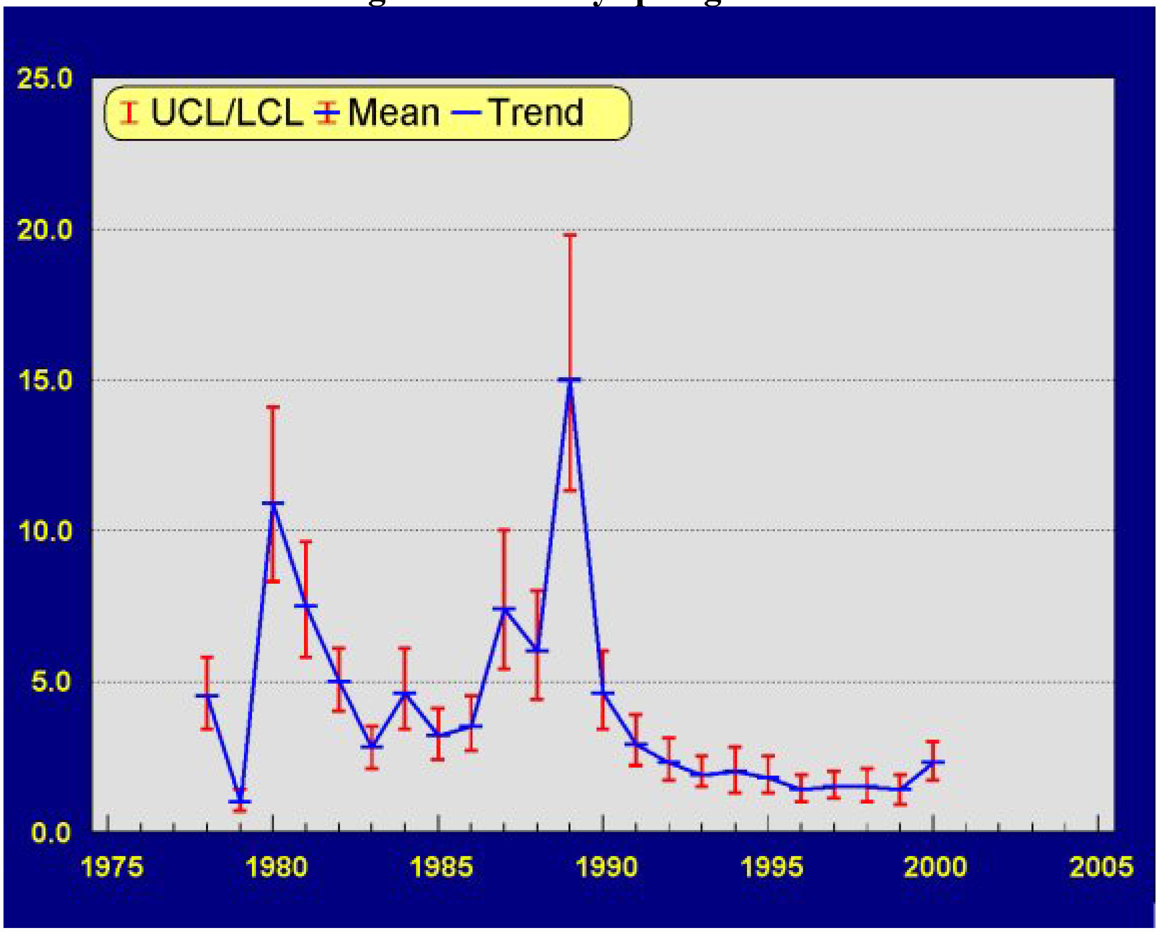
UCL Upper confidence limit

LCL Lower confidence limit

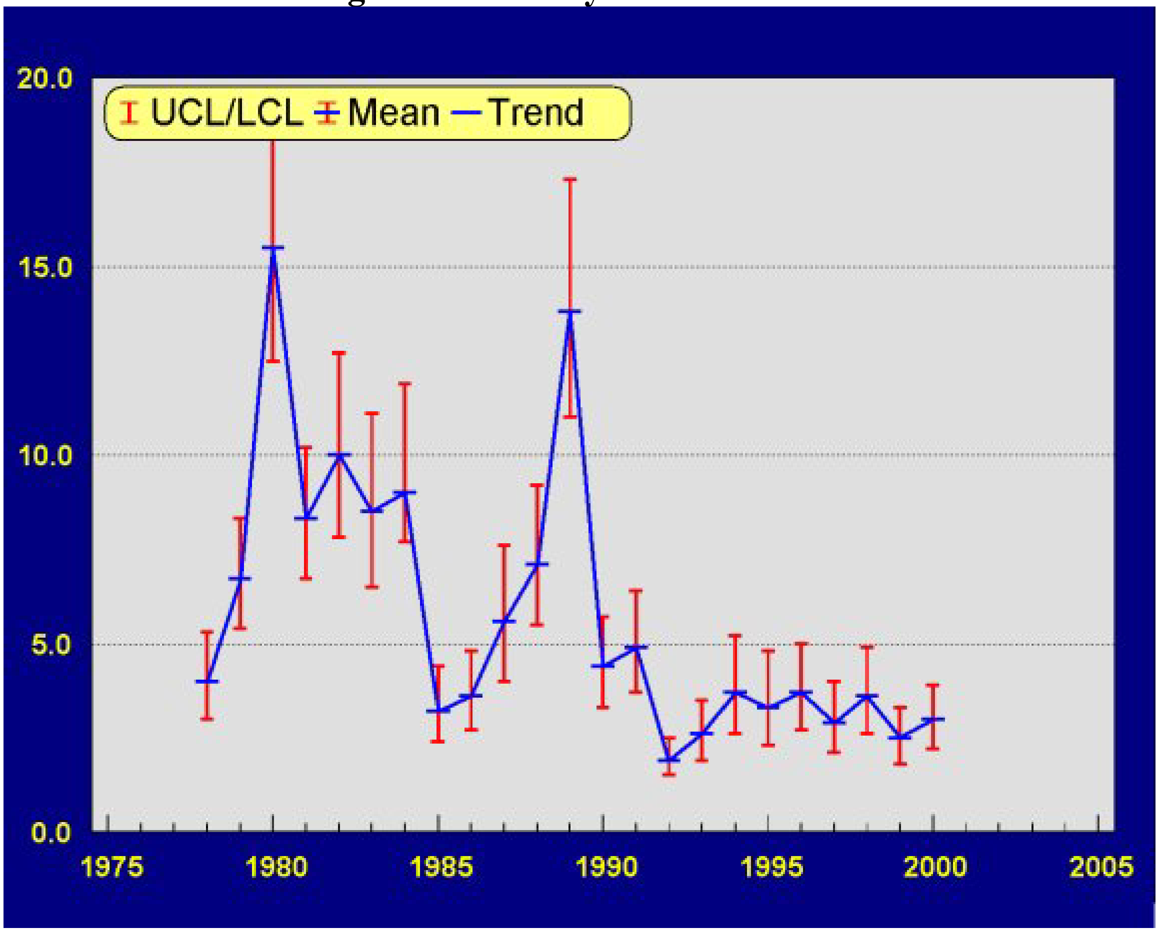
Age 0- rivers only spring index



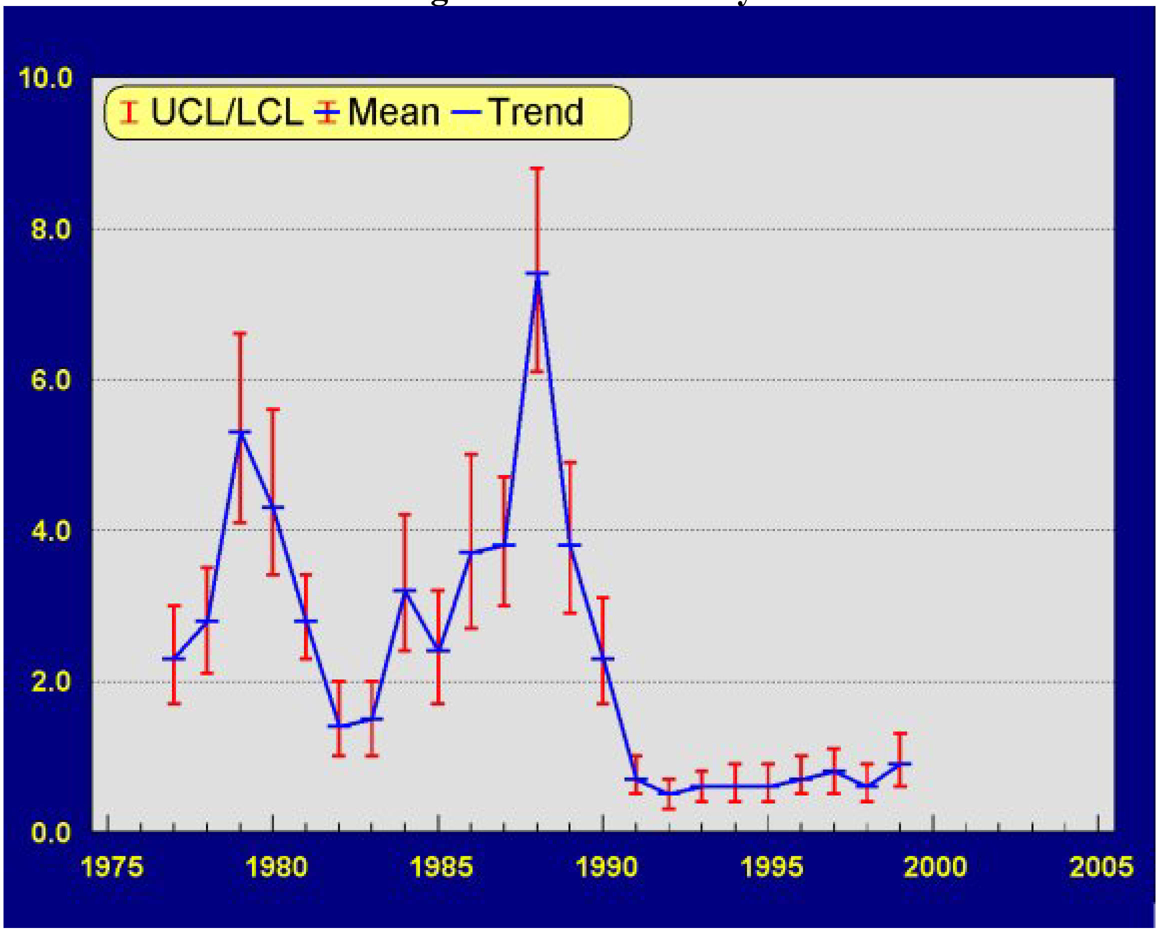
Age 1 rivers only spring index



Age 1- rivers only summer index



Age 2+ in Rivers Only



NATIONAL MARINE FISHERIES SERVICE

Mid Atlantic States Blue Crab Harvest

NMFS Landings Query Results

- Year: From: 1980 To: 2002
- Species: crab, blue
- State: Middle Atlantic

Year	Species	Metric Tons	Pounds	$
1980	CRAB, BLUE	1,913.3	4,218,000	1,592,539
1980	CRAB, BLUE, PEELER	7.1	15,700	9,213
1980	CRAB, BLUE, SOFT AND PEELER	11.5	25,400	48,064
1981	CRAB, BLUE	1,155.7	2,547,900	826,292
1981	CRAB, BLUE, PEELER	21.6	47,700	49,544
1981	CRAB, BLUE, SOFT AND PEELER	25.3	55,800	80,381
1982	CRAB, BLUE	731.1	1,611,800	582,508
1982	CRAB, BLUE, PEELER	4.4	9,800	11,402
1982	CRAB, BLUE, SOFT AND PEELER	6.2	13,700	29,613
1983	CRAB, BLUE	1,128.5	2,487,800	1,025,893
1983	CRAB, BLUE, PEELER	8.0	17,600	25,120
1983	CRAB, BLUE, SOFT AND PEELER	5.3	11,600	19,548
1984	CRAB, BLUE	1,322.1	2,914,800	1,205,152
1984	CRAB, BLUE, PEELER	13.7	30,200	40,980
1984	CRAB, BLUE, SOFT AND PEELER	18.0	39,700	64,096
1985	CRAB, BLUE	2,443.5	5,386,970	2,095,188
1985	CRAB, BLUE, PEELER	46.0	101,400	142,767
1985	CRAB, BLUE, SOFT AND PEELER	17.5	38,500	62,199
1986	CRAB, BLUE	2,658.5	5,861,000	2,297,024
1986	CRAB, BLUE, PEELER	40.8	90,000	111,607
1986	CRAB, BLUE, SOFT AND PEELER	37.5	82,600	136,892
1987	CRAB, BLUE	3,190.4	7,033,565	2,754,658

1987	CRAB, BLUE, PEELER	33.7	74,200	89,103
1987	CRAB, BLUE, SOFT AND PEELER	19.6	43,100	65,044
1988	CRAB, BLUE	4,063.7	8,958,760	4,113,173
1988	CRAB, BLUE, PEELER	108.0	238,100	320,317
1988	CRAB, BLUE, SOFT AND PEELER	71.2	157,000	307,734
1989	CRAB, BLUE	5,147.6	11,348,400	5,117,452
1989	CRAB, BLUE, PEELER	81.1	178,900	236,220
1989	CRAB, BLUE, SOFT AND PEELER	53.1	117,000	300,924
1990	CRAB, BLUE	5,462.3	12,042,214	5,024,323
1990	CRAB, BLUE, PEELER	143.8	316,946	284,829
1990	CRAB, BLUE, SOFT AND PEELER	88.7	195,500	331,564
1991	CRAB, BLUE	5,672.0	12,504,522	5,061,897
1991	CRAB, BLUE, PEELER	22.5	49,524	51,277
1991	CRAB, BLUE, SOFT AND PEELER	11.1	24,400	61,000
1992	CRAB, BLUE	5,187.3	11,435,824	5,640,733
1992	CRAB, BLUE, PEELER	168.8	372,182	371,688
1992	CRAB, BLUE, SOFT AND PEELER	200.5	442,000	654,160
1993	CRAB, BLUE	6,850.5	15,102,581	8,005,089
1993	CRAB, BLUE, PEELER	100.0	220,506	275,141
1993	CRAB, BLUE, SOFT AND PEELER	128.3	282,900	297,045
1994	CRAB, BLUE	5,546.7	12,228,295	7,883,358
1994	CRAB, BLUE, PEELER	203.1	447,695	577,965
1994	CRAB, BLUE, SOFT AND PEELER	138.3	304,800	493,996
1995	CRAB, BLUE	7,252.5	15,988,910	12,749,140
1995	CRAB, BLUE, PEELER	669.4	1,475,814	1,751,966
1996	CRAB, BLUE	4,347.3	9,584,146	6,370,724
1996	CRAB, BLUE, PEELER	201.3	443,816	738,802
1997	CRAB, BLUE	4,909.8	10,824,180	7,101,392
1997	CRAB, BLUE, PEELER	167.2	368,626	704,999

1998	CRAB, BLUE	5,007.2	11,038,851	9,100,122
1998	CRAB, BLUE, PEELER	219.7	484,257	918,922
1998	CRAB, BLUE, SOFT AND PEELER	88.1	194,330	423,708
1999	CRAB, BLUE	4,657.2	10,267,194	8,653,797
1999	CRAB, BLUE, PEELER	148.8	328,130	698,718
1999	CRAB, BLUE, SOFT AND PEELER	42.9	94,601	223,383
2000	CRAB, BLUE	4,699.7	10,360,932	10,568,171
2000	CRAB, BLUE, PEELER	103.8	228,906	565,246
2000	CRAB, BLUE, SOFT AND PEELER	34.9	76,849	187,027
2001	CRAB, BLUE	4,401.2	9,702,778	9,747,857
2001	CRAB, BLUE, PEELER	159.5	351,686	842,313
2002	CRAB, BLUE	4,095.7	9,029,379	9,601,333
2002	CRAB, BLUE, PEELER	104.1	229,470	551,516
2002	CRAB, BLUE, SOFT AND PEELER	16.3	35,870	85,850
GRAND TOTALS:	-	95,634.4	210,835,609	140,359,698

NATIONAL MARINE FISHERIES SERVICE

Chesapeake Bay Blue Crab Harvest

NMFS Landings Query Results

You Asked For the Following:

- Year : From: 1980 To: 2002
-
- Species : crab, blue
-
- State : Chesapeake
-

Year	Species	Metric Tons	Pounds	$
1980	CRAB, BLUE	28,574.7	62,995,800	12,824,504
1980	CRAB, BLUE, PEELER	138.2	304,600	200,902
1980	CRAB, BLUE, SOFT AND PEELER	669.4	1,475,700	1,824,071
1981	CRAB, BLUE	45,088.0	99,400,900	23,634,427
1981	CRAB, BLUE, PEELER	78.6	173,300	166,763
1981	CRAB, BLUE, SOFT AND PEELER	1,246.4	2,747,800	3,448,226
1982	CRAB, BLUE	38,665.9	85,242,900	21,790,449
1982	CRAB, BLUE, PEELER	219.0	482,800	390,523
1982	CRAB, BLUE, SOFT	1.9	4,100	6,905
1982	CRAB, BLUE, SOFT AND PEELER	1,261.0	2,779,900	3,623,190
1983	CRAB, BLUE	42,962.1	94,714,200	28,147,499
1983	CRAB, BLUE, PEELER	283.7	625,400	785,146
1983	CRAB, BLUE, SOFT	14.5	31,900	61,586
1983	CRAB, BLUE, SOFT AND PEELER	1,788.4	3,942,800	5,538,107
1984	CRAB, BLUE	43,665.9	96,265,800	27,158,844
1984	CRAB, BLUE, PEELER	401.3	884,700	1,012,418
1984	CRAB, BLUE, SOFT	17.8	39,300	53,019

1984	CRAB, BLUE, SOFT AND PEELER	914.0	2,014,900	4,095,695
1985	CRAB, BLUE	43,640.4	96,209,580	26,392,152
1985	CRAB, BLUE, PEELER	474.4	1,045,800	1,081,267
1985	CRAB, BLUE, SOFT	24.0	52,900	63,557
1985	CRAB, BLUE, SOFT AND PEELER	1,372.9	3,026,800	6,128,158
1986	CRAB, BLUE	38,843.9	85,635,200	27,283,197
1986	CRAB, BLUE, PEELER	303.5	669,000	686,300
1986	CRAB, BLUE, SOFT	18.7	41,300	78,003
1986	CRAB, BLUE, SOFT AND PEELER	972.0	2,142,900	3,753,974
1987	CRAB, BLUE	34,599.6	76,278,300	29,118,926
1987	CRAB, BLUE, PEELER	192.5	424,400	522,222
1987	CRAB, BLUE, SOFT	22.4	49,400	145,354
1987	CRAB, BLUE, SOFT AND PEELER	883.2	1,947,000	4,866,297
1988	CRAB, BLUE	36,484.1	80,432,800	31,999,741
1988	CRAB, BLUE, PEELER	83.8	184,700	188,695
1988	CRAB, BLUE, SOFT	3.8	8,300	31,723
1988	CRAB, BLUE, SOFT AND PEELER	949.2	2,092,700	3,668,858
1989	CRAB, BLUE	40,214.4	88,656,600	35,049,050
1989	CRAB, BLUE, PEELER	428.2	943,900	1,451,559
1989	CRAB, BLUE, SOFT	108.5	239,200	882,295
1989	CRAB, BLUE, SOFT AND PEELER	625.9	1,379,900	4,339,996
1990	CRAB, BLUE	45,265.7	99,792,849	37,204,123
1990	CRAB, BLUE, PEELER	439.4	968,800	1,239,847
1990	CRAB, BLUE, SOFT	69.4	152,940	571,392
1990	CRAB, BLUE, SOFT AND PEELER	718.9	1,584,916	4,411,192
1991	CRAB, BLUE	42,337.4	93,336,970	29,178,741
1991	CRAB, BLUE, PEELER	364.8	804,275	859,659
1991	CRAB, BLUE, SOFT	56.1	123,661	479,269
1991	CRAB, BLUE, SOFT AND PEELER	1,019.6	2,247,725	4,718,204

1992	CRAB, BLUE	23,806.4	52,483,529	23,989,305
1992	CRAB, BLUE, PEELER	145.6	321,038	590,651
1992	CRAB, BLUE, SOFT	103.6	228,324	855,074
1992	CRAB, BLUE, SOFT AND PEELER	455.8	1,004,940	2,624,107
1993	CRAB, BLUE	50,425.5	111,168,011	63,009,899
1993	CRAB, BLUE, PEELER	688.2	1,517,254	2,601,117
1993	CRAB, BLUE, SOFT	122.5	270,041	1,278,253
1993	CRAB, BLUE, SOFT AND PEELER	839.4	1,850,517	5,099,309
1994	CRAB, BLUE	35,815.0	78,957,784	56,469,607
1994	CRAB, BLUE, PEELER	581.9	1,282,768	2,377,168
1994	CRAB, BLUE, SOFT	66.6	146,934	607,470
1994	CRAB, BLUE, SOFT AND PEELER	746.5	1,645,658	5,431,313
1995	CRAB, BLUE	33,259.7	73,324,416	57,035,814
1995	CRAB, BLUE, PEELER	745.3	1,643,151	3,712,349
1995	CRAB, BLUE, SOFT	849.0	1,871,703	5,628,426
1996	CRAB, BLUE	31,612.5	69,692,924	45,889,136
1996	CRAB, BLUE, PEELER	741.2	1,634,054	3,384,999
1996	CRAB, BLUE, SOFT	837.9	1,847,265	7,950,804
1997	CRAB, BLUE	36,730.8	80,976,676	60,895,717
1997	CRAB, BLUE, PEELER	923.6	2,036,109	3,688,241
1997	CRAB, BLUE, SOFT	738.0	1,626,917	7,399,604
1998	CRAB, BLUE	27,983.8	61,693,074	49,544,105
1998	CRAB, BLUE, PEELER	1,107.9	2,442,525	5,734,872
1998	CRAB, BLUE, SOFT	605.2	1,334,132	6,186,003
1999	CRAB, BLUE	28,647.8	63,156,974	52,178,039
1999	CRAB, BLUE, PEELER	945.9	2,085,370	5,028,145
1999	CRAB, BLUE, SOFT	23.5	51,750	281,067
1999	CRAB, BLUE, SOFT AND PEELER	686.8	1,514,013	7,896,529
2000	CRAB, BLUE	21,858.4	48,188,991	42,223,555
2000	CRAB, BLUE, PEELER	940.9	2,074,348	5,475,504
2000	CRAB, BLUE, SOFT	16.9	37,205	82,713
2000	CRAB, BLUE, SOFT AND	631.7	1,392,648	7,175,351

	PEELER			
2001	CRAB, BLUE	21,278.3	46,910,216	42,259,773
2001	CRAB, BLUE, PEELER	1,058.5	2,333,502	8,162,395
2001	CRAB, BLUE, SOFT	20.3	44,690	181,338
2001	CRAB, BLUE, SOFT AND PEELER	772.1	1,702,131	9,677,413
2002	CRAB, BLUE	22,865.9	50,410,062	40,320,539
2002	CRAB, BLUE, PEELER	954.1	2,103,513	4,609,057
2002	CRAB, BLUE, SOFT	14.3	31,616	116,869
2002	CRAB, BLUE, SOFT AND PEELER	560.6	1,235,891	6,375,046
GRAND TOTALS:	-	847,714.9	1,868,872,280	1,045,182,701

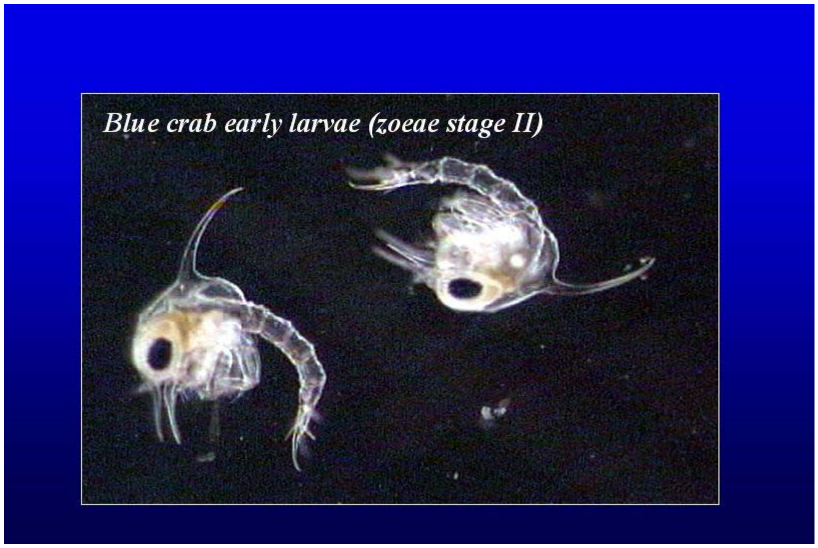
Appendix D

Blue Crab Aquaculture

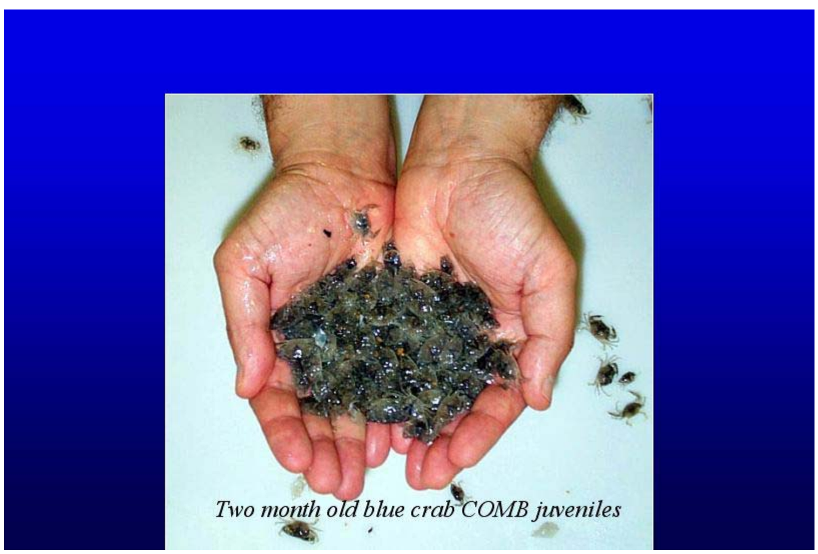
Blue Crab Research at COMB

In just two years since the inception of an innovative research and development effort, COMB scientists were able to close the entire life cycle of the Chesapeake blue crab in captivity and to mass-produce thousands of 20 mm (0.75 inch) juvenile crabs in laboratory tanks. In a joint project with our partners at the Smithsonian Environmental Research Center (SERC), over 25,000 of the COMB crabs were individually

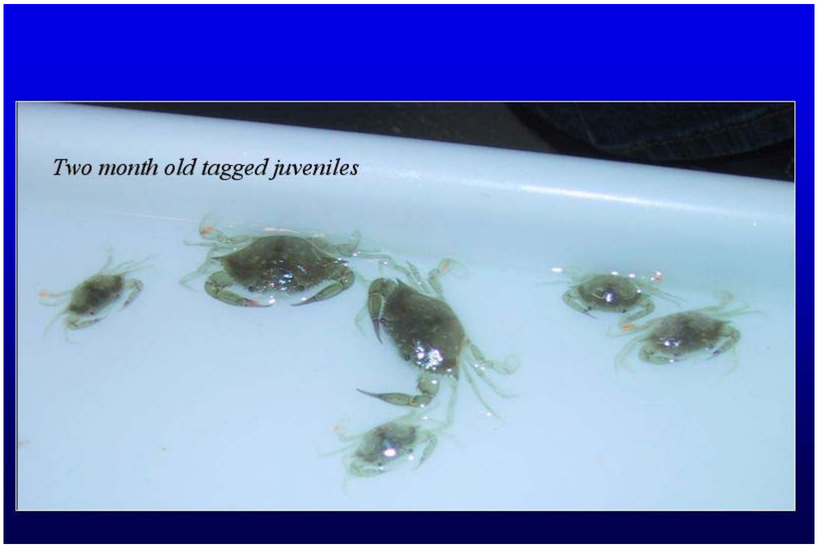
tagged and released to the Chesapeake Bay, where they are monitored for survival, growth, habitat use and movement patterns. This work is part of a multidisciplinary research program aimed at better understanding the basic biology of the blue crab and examining the potential of replenishing its declining fishery. The program was initiated in the summer of 2000 through funding from the State of Maryland and Phillips Seafood Inc. and the efforts of the Maryland Watermen's Association. Additional Federal funding provided through the Chesapeake Bay Office of NOAA, enabled the expansion of the research and the formation of the Blue Crab Advanced Research Consortium (BCARC), which also includes the States of Virginia (Virginia Institute of Marine Sciences), North Carolina (North Carolina State University) and Mississippi (University of Southern Mississippi).



This program was initiated in response to the sharp declines in blue crab harvests over recent years. The first and foremost objective is to unveil the poorly understood, yet complex, basic biology and life cycle of this economically and ecologically important crustacean. We are applying, for the first time, the tools of modern biology to better understand the fundamental processes involved in blue crab reproduction, early development, molting, growth and aggression and also to develop blue crab hatchery technologies. We are releasing individually tagged hatchery crabs to investigate behavior, growth, habitat requirements, and survival of blue crabs in the Chesapeake Bay as well as to assess the potential of rebuilding the reduced Chesapeake stocks.



The partnership's researchers started with mated Chesapeake Bay blue crab females. Placed in marine tanks at COMB's Aquaculture Research Center, the crabs were exposed to phase-shifted environmental conditions, which resulted in year-round spawning. Individual females spawned several million free-swimming blue crab larvae. The larvae were fed with microscopic algae and zooplanktonic organisms and went through 9 larval stages before metamorphosing into tiny crabs at 4 weeks of age. Optimizing the complex feeding regimen of the larvae resulted in excellent survival rates through larval rearing of up to 70%. The next hurdle is that the tiny crabs use their claws to attack their siblings. Experiments carried out



to reduce aggression and cannibalism demonstrated that providing shelter structures, ample amounts of diversified food, enough “elbow room”, as well as sorting the baby crabs by size, resulted in excellent survival rates of the tiny crabs. Analyses are being performed to determine the optimal balance between maximizing the tank densities and maximizing survival rates, in an effort to scale up the cost-effective mass production of juvenile crabs. At intensive conditions, around 45-50% of the baby crabs survived through 6-7 captive molts to reach 20 mm of size by 9 weeks of age. It took COMB scientists a little over a year to optimize the culture parameters and develop intense hatchery technologies to produce thousands of healthy juvenile crabs for the ongoing studies of the blue crab life cycle and of rebuilding the reduced Chesapeake population. It is important to note that these crabs retain the unaltered genetic composition of their Chesapeake parents.

Over the summer of 2002, COMB produced 40,000 juvenile crabs (0.5-1.5 inches in size). Twenty-five thousand of those hatchery crabs were individually tagged and released to study sites in the wild by SERC scientists. To distinguish hatchery crabs from wild crabs, all hatchery crabs are tagged before release. We have tested and employed two methods for tagging crabs that will last through the series of molts as small hatchery crabs grow: tiny injections of either colored plastic (see photo) or magnetized wire. COMB scientists are now developing new genetic identification approaches to monitor hatchery and wild crabs, using DNA fingerprinting technologies.

SERC scientists have followed the groups of tagged hatchery crabs for up to 14 weeks after their release. In this first summer following release, the hatchery crabs have grown to almost 5 inches (12.5 cm) carapace width at the age of 6 months. At this size, the crab is approaching maturity and will soon be able to contribute reproductively to the Bay's blue crab population. Future research will also test for optimal conditions and procedures for survival, growth and migration to spawning areas by hatchery crabs. VIMS and SERC scientists are also using small crabs caught in the Bay to release at study sites to test the feasibility of increasing crab abundance. These experiments will allow further comparisons of hatchery-reared crabs with wild crabs.

Initial experiments show that hatchery crabs behave similarly to wild crabs. For example, COMB crabs raised on a hatchery diet readily begin feeding on natural prey at rates similar to wild crabs.
Other experiments are teaching us ways to promote survival of released hatchery crabs. Crabs reared in hatchery tanks without bottom sediments have lower survival until they gain experience burying to escape predators. We are testing procedures to give hatchery crabs experience with natural sediments prior to release.

Based on the findings of the ongoing and future research, we plan to establish a large-scale blue crab prototype hatchery/nursery to be used for studies of blue crab biology and ecology and for testing the feasibility of stock enhancement in the Bay.

For more details please contact:

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Researchers are Working to Boost Blue Crab Population.

Oct. 28, 2002
Cincinnati Post, Tampa Tribune, Olympia (Wash.) Olympian, Chicago Sun-Times, Las Vegas Review-Journal, Omaha World
By staff report

Oct. 25-ROANOKE ISLAND, N.C.-Tucked away in a makeshift hatchery in the back of the North Carolina Aquarium, conservation and research coordinator Joanne Harcke has been working for almost a year to reproduce the optimum living environment for the larvae of blue crabs.

Not far away, **North Carolina State University Associate Professor David Eggleston** is searching for ways to introduce wild blue-crab larvae into underused nursery areas of the Albemarle and Currituck sounds.

Together the two projects funded by the North Carolina Sea Grant Blue Crab Research Program could provide a boost to the state's troubled blue-crab industry by enhancing stocks, possibly even leading to blue-crab aquaculture.

Ten months after putting together the hatchery, Harcke can see the fruits of her labor as about 100 juvenile crabs feast on frozen shrimp. The crustaceans are one of the first groups of blue crabs in the country to have successfully gone through eight molting stages outside of their traditional surroundings.

"Our work shows it is feasible to raise blue crabs through the juvenile stage in a captivity setting," Harcke said as she stood in her small laboratory cluttered with beakers, holding tanks and microscopes.

To local crabber Murray Bridges of Endurance Seafood, the work of the researchers could translate into benefits for the blue-crab industry, the state's most lucrative fishery.

"Naturally, the more crabs you put in the water, the better off you are," he said. "And it does open the door for raising crabs as an aquaculture, just like you raise fish like striped bass and catfish."

Blue-crab landing counts have been down for the past three years, reaching about 55.9 million pounds in 1999 but plummeting to 30 million pounds in 2001. North Carolina Division of Marine Fisheries Biologist Supervisor Sean McKenna said it's unclear whether the decline is biologically or environmentally driven.

Harcke's $63,000 project and Eggleston's $38,000 study are among a handful of projects sponsored by the program, which is looking at ways to enhance blue-crab stocks.

"It's not necessarily rocket science," Harcke said as she explained how she has raised the larvae through the molting stages to the juvenile crabs that now sit in separate pipes in tanks to protect them from their own cannibalistic habits.

Undisturbed, the tiny crabs happily munch on their shrimp, putting all their energy into growing rather than protecting themselves from predators and other dangers of the sounds and estuaries.

Except for a similar study under way at the University of Maryland that also appears to be enjoying success, Harcke said, this is the first time this type of culture of blue crabs has been done.

Harcke, after first receiving female sponge crabs from local crabbers in April, has developed feeding regimes and techniques for raising the crabs in what are called the zoea and megalopa stages. Staci Shaut, a student at the University of North Carolina at Chapel Hill, assisted Harcke in the study.

Harcke initially fed the larvae two types of live algae she raises in the lab. As the crabs grew, she increased the size of their feed, first giving them microscopic animals called rotifers, then brine shrimp.

"We are re-creating the food chain in an artificial setting," she said.

The next step, she said, is to scale up the techniques she has implemented by experimenting with the large-scale production of several thousand blue crabs. Harcke said she plans to explore two avenues with new grant money - introducing hatchery crabs into the wild and also attempting to grow them to market size in the hatchery.

Eggleston's work involves catching wild larvae with plankton nets and moving them to underused nursery areas.

While promising, Eggleston said, the aquaculture of blue crabs is not without challenges.

"Animals that spend their entire lives in a hatchery environment don't do very well in the wild, but there are ways to mitigate that," he said. "You can expose hatchery-reared animals to predators to improve their behavioral skills."

One major roadblock is that once they reach the juvenile stage, the crustaceans become cannibalistic.

"It remains to be seen whether a high density of crabs released into a nursery habitat are going to survive," he said, but added that his work so far showed that in the short term, the wild ones that have been relocated are surviving.

Another significant hurdle in releasing hatchery juveniles into the wild is being able to tell them from their wild counterparts. That would mean devising a tagging system to identify the hatchery crabs.

"But there is certainly the potential to augment the stock using hatcheries if you can overcome the behavioral hurdles and tagging hurdles," he said.

Eric Johnson, an N.C. State graduate student working with Eggleston, said blue-crab aquaculture could allow crabbers to set the market time and price by raising the crustaceans during the winter when there is not much of a market. Crab shedders, he said, could also operate their businesses year-round.

McKenna, who was a bit more cautious about the feasibility of blue-crab aquaculture, said the mortality rate in blue crabs does not appear to be occurring in the juvenile population but later on.

Regardless of the impact the projects may have on stock enhancement, Eggleston said, the goal is to conserve the wild population.

"We can't view stock enhancement as a technological fix," he said. "We need to put conservation of the wild stock as the first priority."

For more information, contact Doug Lipton, dlipton@arec.umd.edu

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