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Abstract

Sanctuaries can potentially protect a significant fraction of the spawning stock, and thereby sustain heavily exploited populations. Despite the worldwide use of marine and estuarine spawning sanctuaries, the effectiveness of such sanctuaries remains untested. We therefore attempted to quantify the effectiveness of the spawning sanctuaries for adult female blue crabs (*Callinectes sapidus*) in Chesapeake Bay. We used baywide winter dredge survey data to estimate the potential spawning stock prior to the major exploitation period, and summer trawl survey data to estimate spawning stock abundance within the Lower Bay Spawning Sanctuary and adjacent Bayside Eastern Shore Sanctuary during the reproductive period. Hence, we were able to approximate the percentage of the potential spawning stock that was protected by both sanctuaries after exploitation. On average, approximately 16% of the potential spawning stock survived to reach the Lower Bay Spawning Sanctuary and Bayside Eastern Shore Sanctuary. Even under a best-case scenario (i.e., crab residence time of 2 weeks), the sanctuaries only protected an estimated 22% of the potential spawning stock, which is well below the percentage recommended by recent stock assessments for sustainable exploitation (28%). In the worst case, a mere 11% of the potential spawning stock survived to reach the spawning sanctuaries. Hence, we recommend a substantial expansion of the spawning sanctuaries, as well as the complementary protection of other life stages

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in critical habitats, such as nursery grounds and dispersal corridors. Furthermore, traditional fisheries management measures (e.g., effort control) should be used in concert with sanctuaries to thwart impediments to effective implementation of the sanctuaries, such as redirected fishing effort.

Introduction

Use of Marine Reserves

Fishing can drastically reduce the abundance of exploited stocks by growth or recruitment overfishing (Bohnsack 1990, Roberts and Polunin 1991). Similarly, environmental disturbances such as hurricanes can disrupt even the most productive ecosystems (Knowlton 1992, Hughes 1994, Butler et al. 1995). Their effects can be catastrophic, causing either dramatic population decline (e.g., Hughes 1994) or transitions between alternative states (Knowlton 1992). Marine reserves and sanctuaries can potentially moderate these impacts, enhance stocks, and facilitate long-term, sustainable exploitation (Davis 1977, Alcala and Russ 1990, Bohnsack 1993, Carr and Reed 1993, Roberts and Polunin 1993, Tegner 1993, Rakitin and Kramer 1996, Russ and Alcala 1996) by increasing abundance, average size, reproductive output, recruitment, and genetic diversity (Dugan and Davis 1993).

There is much evidence, though primarily descriptive, that details significant increases in abundance and average size of fishery species within reserves (Gitschlag 1986, Alcala 1988, Davis and Dodrill 1989, Funicelli et al. 1989, Rutherford et al. 1989, Alcala and Russ 1990, Bohnsack 1990, Yamasaki and Kuwahara 1990, Rakitin and Kramer 1996, Russ and Alcala 1996). The two major postulated benefits of this phenomenon to fishery stocks include (1) enhancement of the spawning stock, which subsequently magnifies recruitment of larvae, postlarvae, and juveniles to reserve and non-reserve areas; and (2) export of biomass to non-reserve areas when exploitable individuals migrate from protected areas to the fishing grounds (Bohnsack 1990, Polunin and Roberts 1993, Hastings and Botsford 1999, Sladek-Nowlis and Roberts 1999).

Simple prohibition of exploitation in a refuge or sanctuary does not ensure that target species will recover (Dugan and Davis 1993). Where the abundance and size of target species do not differ between reserve and exploited areas, the similarity in estimates may be due to improper sampling design, migrations outside protected zones, or the lack of critical habitats within reserves (Polachek 1990, Dugan and Davis 1993). For example, when spawner sanctuaries were established in marginal habitats, trochus snail (*Trochus niloticus*) and hard clam (*Mercenaria mercenaria*) populations did not increase (Helsinga et al. 1984, McCay 1988). Hence, empirical estimates of the impact of marine reserves or sanctuaries upon the target species are required to validate and assess the utility of the reserves. Although marine reserves and sanctuaries have become popularized as conservation tools, their effectiveness in sustaining or enhancing marine fisheries remains virtually untested (Allison et al. 1998). Thus, we assessed the efficacy of spawning sanctuaries for the blue crab spawning stock in lower Chesapeake Bay.

Blue Crab Life History and Ecology in Chesapeake Bay

The blue crab, *Callinectes sapidus* Rathbun (Arthropoda: Crustacea: Portunidae), is dispersed widely along the Atlantic and Gulf coasts of North America, and has been abundant throughout Chesapeake Bay (Williams 1984, Hines et al. 1987, Lipcius and Van Engel 1990). This species is important in energy transfer in estuaries, serving as both omnivore and prey (Baird and Ulanowicz 1989). The diet of blue crabs consists mainly of bivalve mollusks, and includes conspecifics, polychaetes, other crabs, and fish (Laughlin 1982, Alexander 1986, Hines et al. 1990, Mansour and Lipcius 1991, Ebersole and Kennedy 1995).

The life history of the blue crab (Fig. 1, illustration provided by J. van Montfrans and R. Orth, Virginia Institute of Marine Science) is complex and bears upon the efficacy of sanctuaries for this species. Mating typically occurs from May through October, whereby a male couples with a female that is approaching her terminal molt to maturity. When the female undergoes the terminal molt and is in the soft-shell stage, the pair mates and the male protects the female until her shell hardens (Van Engel 1958).

After mating, females begin a migration toward the lower bay where they will eventually spawn and release their larvae in higher salinities. Those females that reach the Lower Bay Spawning Sanctuary (LBSS) and adjacent Bayside Eastern Shore Sanctuary (BESS) (Fig. 2) are protected from fishing during 1 June-15 September, which encompasses the reproductive period when most females bear eggs (Jones et al. 1990; Lipcius, unpubl. manuscript). Males do not migrate to the bay mouth, but overwinter in the deeper waters of the rivers and bay mainstem (Van Engel 1958). Some females overwinter within the sediments throughout the bay prior to completing their migration to the lower bay the following spring (Lipcius et al. 2001). Prior to the migration, blue crabs are exploited by various fisheries (e.g., peeler and pot fisheries).

Blue Crab Fisheries and Sanctuaries

The blue crab is fished heavily in Chesapeake Bay (Miller and Houde 1998, Rugolo et al. 1998). Exploitation rates have increased substantially in this decade (Miller and Houde 1998, Rugolo et al. 1998, Lipcius and others, unpubl. manuscript), resulting in a decrease in total catch per unit of effort in both the pot and winter dredge fisheries (Rugolo et al. 1998). Furthermore, the spawning stock has concurrently decreased by over 80% (Lipcius, unpubl. manuscript; Lipcius and others, unpubl. manuscript), suggesting that the population is overexploited. Caution is therefore needed in management of this fishery to avoid a stock collapse.

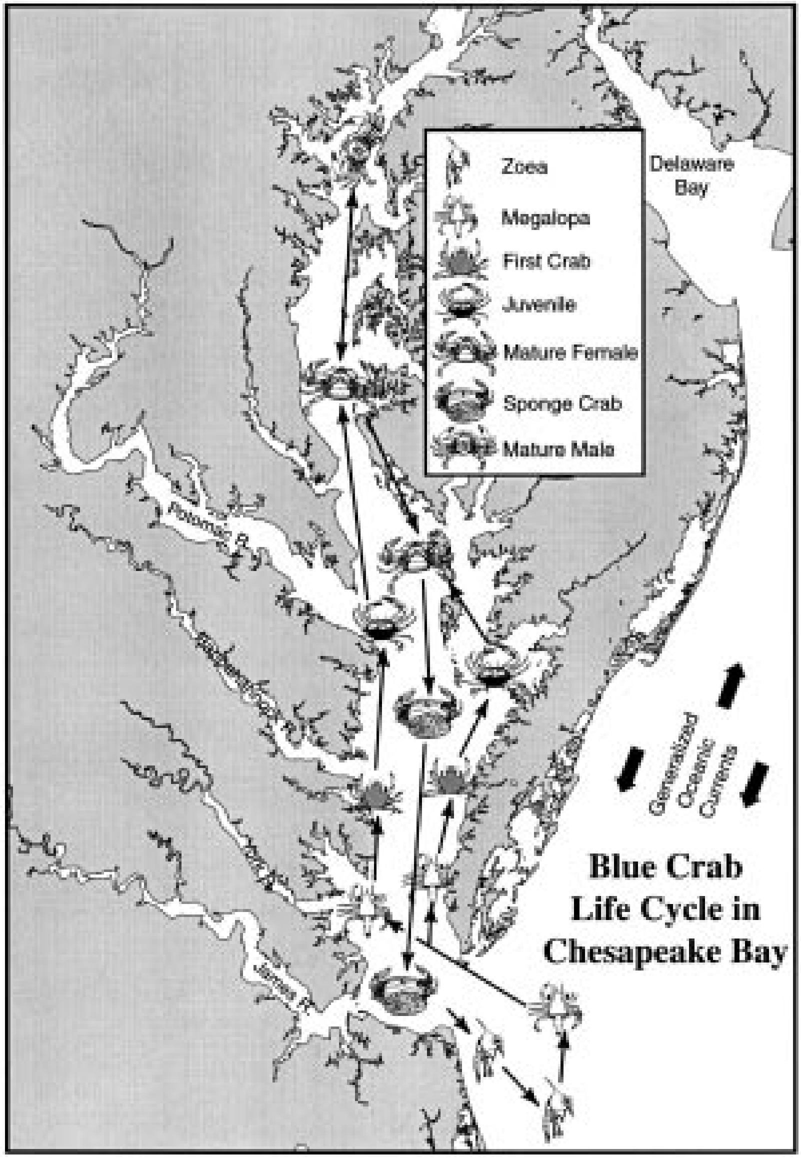

Figure 1. Life history of blue crab in Chesapeake Bay. Large heavy arrows indicate dominant summer water flow. Each stage or position in the bay is represented by a crab symbol (starting from the bay mouth): Larvae develop in coastal currents during summer and early fall; Postlarvae re-enter the estuary and settle in lower bay seagrass beds from mid-summer through early fall; Juvenile crabs develop in seagrass and disperse up tributaries and up-bay in late summer, fall, and the following spring; Crabs mate in the bay's tributaries and shallower mainstem waters from spring through fall; Mated females migrate down-bay; Females spawn egg masses in the lower bay from late spring through summer before hatching their larvae.

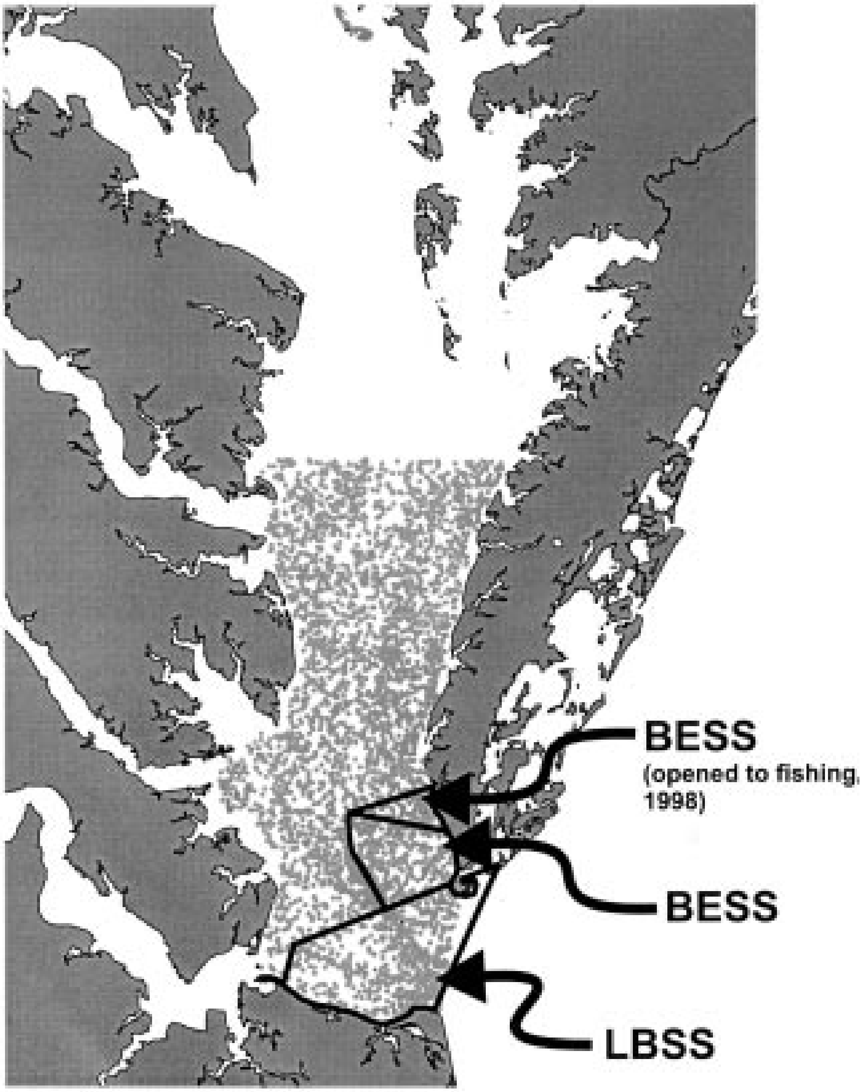

Figure 2. Lower bay blue crab sanctuary boundaries (black line) and Virginia trawl survey sampling sites 1989-1999 (gray dots). Three segments of the sanctuaries are depicted: (1) the Lower Bay Spawning Sanctuary (LBSS), which is closed to crab potting 1 June-15 September; (2) the original Bayside Eastern Shore Sanctuary (BESS), which is closed to crab potting 1 June-15 September; and (3) the current BESS which was reduced in 1998.

Because of its complex life cycle, there are several productive fisheries for the blue crab in Chesapeake Bay characterized by gear and methodology, including (1) pot, (2) winter dredge, (3) scrape, (4) peeler pound and trap, (5) trot line, and (6) recreational gear. The pot fishery (1 April-30 November) targets hard-shelled crabs, both throughout the bay and tributaries of Virginia and in the mainstem bay of Maryland. Trot lines are used exclusively in Maryland tributaries where pots are prohibited. In Virginia, about 83% of the total catch of crabs is taken by the hard crab and peeler pot fisheries (Burreson et al. 2000). The "jimmy pot" fishery is a subset which uses adult males to attract females to pots during the spring and fall when females are mating and migrating to the mouth of the bay to spawn (Van Engel 1958). In Maryland, the pot fishery takes 61-67% of the annual landings and the trot line fishery 30-36% (Burreson et al. 2000). The winter dredge fishery (1 December-31 March) primarily targets recently matured and mated female crabs that bury into the sediment in the deeper waters at the mouth of Chesapeake Bay. This fishery takes about 15% of the total crab catch in the bay (Burreson et al. 2000). The scrape fishery targets juvenile crabs in the seagrass beds mainly near Tangier Island, Virginia and Smith Island, Maryland. The peeler pound and soft crab fisheries target crabs in pre-molt status that are delivered to tanks where they are shed to the soft crab stage, and afterward sold as fresh or frozen soft crabs. Otherwise, these are sold as peelers in the bait trade. Together, the scrape and pound fisheries take only 1-2% of the total crab landings (Burreson et al. 2000). Finally, the year-round recreational fishery targets crabs mostly at the shoreline and removes an estimated additional 15% of the landings (Rob O'Reilly, Virginia Marine Resources Commission [VMRC], Newport News, VA, pers. comm., Dec. 1999).

To prevent overexploitation, Maryland, Virginia, and the District of Columbia have established various controls on the blue crab fisheries. Each fishery is regulated differently depending on whether the crabber is in Maryland, Virginia, or the Potomac River. Commercial crabbing regulations comprise license, gear, and crab size restrictions, catch limits, season, time, or area restrictions such as sanctuaries (Table 1).

One management strategy has been to establish spawning sanctuaries, where crabbing is prohibited for selected time periods. Some sanctuaries in Chesapeake Bay exist for the benefit of the blue crab (e.g., LBSS), whereas others are implied sanctuaries that are delineated for the ease of navigation or fishing. Each crab sanctuary in Chesapeake Bay affects a different segment of the crab population and its associated fishery (Table 1, Fig. 2). Both the LBSS and BESS affect the pot fishery, and are closed to ease fishing pressure upon adult females that have migrated to the lower bay to spawn and release larvae. The LBSS has been in existence for decades (Van Engel 1958); in December 1994, the BESS was established and has protected crabs from 1995 to present. The upper portion of the BESS was removed and opened to fishing in 1998 (Fig 2.) Shipping channels in Virginia are closed to potting to eliminate navigational hazards.

Table 1. Blue crab sanctuaries, both intended and implied, for Maryland and Virginia portions of Chesapeake Bay.

Name of sanctuary or implied sanctuary	Fishery affected	Dates closed	Comments
Lower Bay Spawning Sanctuary and Bayside Eastern Shore Management Area (Virginia)	Pot	1 June-15 Sept.	Closed to crab potting. Dredging begins 1 Dec.
Virginia Shipping Channels (Virginia)	Pot	Year-round	Crab pots prohibited.
Maryland Tributaries (Maryland)	Pot	Year-round	Closed to crab potting. Trot lines allowed.
Virginia Tributaries (Virginia)	Dredge	Year-round	Closed to dredging in river inlets or creeks.
Hampton Roads Sanctuary (Virginia)	Dredge	Year-round	Closed to crab dredging upriver of Hampton Roads Bridge Tunnel.

Objectives

Sound management and sustainable use of a living resource requires a strong ecological foundation (McAllister and Peterman 1992). This investigation provides the first empirical estimate of the percentage of a population protected by a sanctuary; specifically, we examined the efficacy of the LBSS and BESS. We thereby present information that will foster conservation and enhancement of the blue crab stock and its critical habitats in Chesapeake Bay. Our approach involved estimating crab abundance during two time periods. First, a winter dredge survey provided a population-wide estimate of the potential spawning stock (i.e., all adult females and immature females which would mature and spawn the following summer) prior to most exploitation. We reduced the November winter dredge survey estimates by 6 months of natural mortality (0.375 per year for 6 months). Second, a summer trawl survey within the spawning sanctuaries provided an estimate of the number of females that survived exploitation and successfully migrated to the spawning sanctuaries. The second estimate divided by the first yielded an estimate of the annual proportion of the potential spawning stock that survived natural mortality and exploitation to spawn in the spawning sanctuaries (i.e., the efficacy of the sanctuaries).

Methods

Baywide Dredge Survey

The winter dredge survey is conducted throughout Chesapeake Bay and consists of annual sampling at monthly intervals from November through March. The dredge survey sampled the blue crab population using a stratified random design, which divided Chesapeake Bay into three geographic strata: upper, middle, and lower Chesapeake Bay. Since blue crabs bury in the sediments during the winter, thereby sharply restricting their movement, sampling during the winter provides a "snapshot" of the static, sedentary population prior to extensive exploitation in the spring. Some exploitation, however, has occurred in the previous fall after the new year class of crabs has reached an exploitable size.

In the sampling, 1,500 sites deeper than 1.5 m were selected randomly, and apportioned by the area of each stratum. The upper bay stratum included the tributaries, creeks, and upper mainstem of Chesapeake Bay. The middle and lower bay strata encompassed the middle and lower portions of the bay mainstem.

Survey vessels used identical sampling gears: standard "Virginia crab dredges" (width 1.83 m) lined with hexagonal mesh (12.7 mm). At each sampling site, the vessel sampled for 1 minute at a constant speed of ~3 nautical miles per hour. LORAN or GPS coordinates were recorded at tow start and end points and were later used to calculate mean distance covered. Each crab was measured (carapace width [cw] in millimeters), and the sex, maturity, and overall condition recorded.

The stratified random survey was implemented following standard methods (Lipcius and Montane 1997). Efficiency experiments were conducted annually to provide catchability coefficients used in calculations of absolute abundance (Lipcius and Montane 1997).

From the dredge survey November data, we summed the 1+ immature females (females > 60 mm cw, but without the circular abdomen characterizing adult females) and adult females (all females with a circular abdomen, regardless of size) to represent the potential spawning stock. This spawning stock estimate was not the full potential spawning stock, as a small segment of it had been fished prior to the dredge survey. Consequently, our estimates of the proportion of the potential spawning stock reaching the sanctuaries were liberal. We then multiplied the November spawning stock by the natural mortality rate of 0.375 per year $\times$ 6/12 months to get the spawning stock after 6 months of natural mortality.

Virginia Trawl Survey

Field Sites and Sampling

Blue crab adult females release larvae in the lower reaches of Chesapeake Bay each year from June through mid-September (Van Engel 1958, Jones et al. 1990, van Montfrans et al. 1995). Hence, an accurate measure of the spawning stock necessarily involves sampling of adult females in the spawning grounds of lower Chesapeake Bay from June through September. Our trawl samples were taken monthly in the lower bay spawning grounds (Fig. 2) from June through September and provide an estimate of the spawning stock.

Density

Adult female blue crabs were sampled with a stratified random trawl survey in the lower bay. Details of sampling are given by Lipcius and Van Engel (1990), Hata (1997), and Lipcius (unpubl. manuscript). Each density value from a single 5-minute tow served as an independent datum (i.e., number of adult females per tow); annual sample sizes usually averaged about 50 tows. Density was analyzed as the arithmetic mean number of adult females per tow.

There were no trawls taken in the LBSS in August 1998, or in the BESS in August 1995 or 1998. For years where samples were taken in all 4 months, there were significant correlations between the total abundance over all months in which the sanctuary was in effect (sum from June, July, August, and September) and the total abundance in all months excluding August. Therefore, regression equations (LBSS: Total = 1180442 + 1.07 × [Total–August], r^2 = 0.69, P = 0.003; and BESS: Total = 355903 + 0.629 × [Total–August], r^2 = 53.3, P = 0.04) were used to replace the missing August abundances. In analyses with these data, the degrees of freedom were reduced by the number of these samples.

We calculated adult female abundance within LBSS and BESS from trawl survey data. Densities were converted to abundances using each sanctuary's area and an overall trawl efficiency of 22%, which was measured for equivalent gear in Chesapeake Bay habitats (Homer et al. 1980). The 22% trawl efficiency estimate is sound, since Homer et al. (1980) used the DeLury cumulative catch method; repetitive 500 m trawls were made in a small discharge canal of the Chalk Point Power Plant in the Patuxent River, Maryland until the rate of decrease between consecutive hauls approached zero (~10 trawls). Furthermore, movements of fish and crabs into and out of the canal were minimal during daytime when efficiency studies were conducted (Homer et al. 1979). Trawl efficiencies for blue crabs averaged 25% in July and 19% in September, yielding a mean efficiency of 22% during the summer and fall (Homer et al. 1980).

Calculations

Crab densities from trawl survey data were converted to abundances as follows: (1) The arithmetic mean monthly density of adult female crabs per trawl was estimated from 1989-1999. (2) The average distance covered during each 5-minute trawl was estimated from 1990-1994 to be 385 meters per trawl (Paul Gerdes, Virginia Institute of Marine Science, Gloucester Point, VA, pers. comm., May 1997). (3) The estimated width of the trawl (5.182 m) was multiplied by the mean distance covered by the trawl to obtain mean area covered by each trawl (5.182 m × 385 m per trawl = 1,995 m^2 per trawl). (4) The mean monthly number of crabs per trawl was multiplied by the area covered by each trawl to obtain density per hectare. For example, in June 1989 in the LBSS, 1.57 crabs per trawl divided by 1,995 m^2 per trawl = 7.88×10^{-4} crabs per m^2 or 7.88 crabs per hectare. (5) The area covered by the LBSS sanctuary is 39,600 hectares, and the area of the BESS was 19,400 hectares for 1995-1997, which was changed to 16,000 hectares for 1998-1999 (Tina Hutcheson, VMRC, Newport News, VA, pers comm., Dec. 1999). This value was then multiplied by each monthly trawl estimate of density to obtain the total number of crabs residing within each sanctuary's bounds in each month. (6) Since trawling is only 22% effective (Homer et al. 1980), each value was multiplied by 4.55 to estimate the absolute number of crabs residing in the sanctuary. (7) Monthly estimates of crab abundance were summed for each year to get an estimate of total annual abundance of crabs in each sanctuary (using only 1995-1999 for the BESS). (8) To account for crab residence time, abundance estimates were multiplied by 1, 1.5, and 2.

Efficacy of the Lower Bay Spawning and Bayside Eastern Shore Sanctuaries

We estimated the efficacy of the blue crab sanctuaries, the LBSS and BESS, by calculating the percentage of all adult females in the Bay that resided within each sanctuary using the following equation:

$$\Sigma\, AF_{sanctuary} / SS_{Bay\text{-}May} = \text{Sanctuary Efficacy}$$

where $\Sigma\, AF_{sanctuary}$ was the sum over 4 months (June-September) of adult female crabs in both sanctuaries (determined from summer trawl surveys) and $SS_{Bay\text{-}May}$ was the potential spawning stock of female crabs, determined from the baywide dredge survey in November and reduced by natural mortality over 6 months (= spawning stock in May).

Our estimates of the spawning stock reflect the number of spawning events, whether by individual females or females spawning multiple times, and are therefore consistent with recent stock assessments (Miller and Houde 1998, Rugolo et al. 1998). These estimates give equal weight to crabs spending a small or large amount of time in the sanctuary, since each crab that enters was assumed to spawn once. After a female spawns within a sanctuary, she leaves, possibly to return and spawn again. Therefore, estimated number of crabs protected by the sanctuary depends upon each crab's residence time in the sanctuary. For example, when sampling is monthly and a crab's residence time is 2 weeks, our sampling underestimates by $^1/_2$ the number of crabs in the sanctuary. Hence, we examined the sensitivity of our estimates to residence time. Our estimates can be recalculated to incorporate new empirical estimates of residence time as these data become available.

Crab residence time within the sanctuary is unknown, but is likely near 2-4 weeks (McConaugha 1992, Prager 1996). To examine the sensitivity of our abundance estimates to residence time, we selected residence times of 2, 3, and 4 weeks. We therefore generated three sets of estimates for crab abundance in the sanctuaries: one for a minimum residence time (2 weeks, multiplication factor of 2), yielding a maximum abundance estimate;one for an average residence time (3 weeks, multiplication factor of 1.5), giving an average crab abundance; and one for a maximum residence time (4 weeks, multiplication factor of 1), yielding a minimum abundance estimate. If, in the future, crab residence time is precisely determined, the most accurate of our three estimates can be used, since our assumptions and calculations for three different residence times are discussed herein. For simplicity, most of the results are portrayed for a mean residence time of 3 weeks.

Finally, using the baywide abundance of all 1+ females available 1 June (which represent the potential spawning stock) and abundance of crabs within each sanctuary, we estimated the percentage of the total spawning stock that reached each of the two sanctuaries (LBSS and BESS) and was therefore protected by them. The fraction of the spawning stock protected by the sanctuaries was calculated as follows: the sum of females in each sanctuary over 4 months ($\Sigma\ AF_{sanctuary}$) was divided by the estimated total number of females in the bay in May ($SS_{Bay\text{-}May}$) to calculate the percentage of the spawning stock that was protected (i.e., sanctuary efficacy).

Densities by Geographic Zone

We also examined crab densities in the two lower bay sanctuaries in relation to the area that was removed from the BESS and opened to fishing in 1998 (Fig. 2) and the rest of the lower bay (not contained within a sanctuary). Samples were not taken in all areas in all months; data from months where sampling in a given area was not conducted were replaced with annual averages from months where sampling was completed. A two-way analysis of variance was performed using area and year as factors; degrees of freedom were reduced by the number of estimated values.

Results

Baywide Female Abundance

The baywide dredge survey abundance of 1+ females at the end of May (from November dredge survey abundance reduced by six months of natural mortality) ranged from a high of 190 million crabs in the 1990/1991 season to a low of 42 million in the 1998-1999 season, with an average of 111.4 ± 15.5 (S.E.) million crabs (Fig. 3). Most of the high annual abundances occurred in or before 1994; those from 1995 to the present were substantially lower.

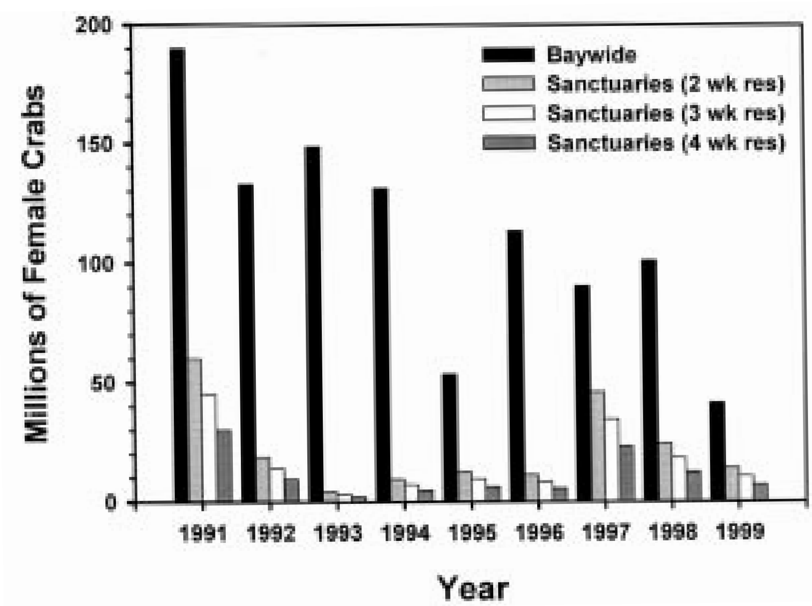

Figure 3. Female crab abundance baywide and within sanctuaries. Annual baywide abundance of 1+ females (mature and immature) is from November winter dredge survey data, 1991-1999 seasons (dark shading). The season of a given year includes November of the previous year (e.g., 1991 season includes November of 1990). Lighter-shaded bars are the abundance of adult females in the Lower Bay Spawning Sanctuary and the Bayside Eastern Shore Sanctuary combined under the assumption of different residence times–multiplication factors of 2 for 2 weeks, 1.5 for 3 weeks, and 1 for 4 weeks.

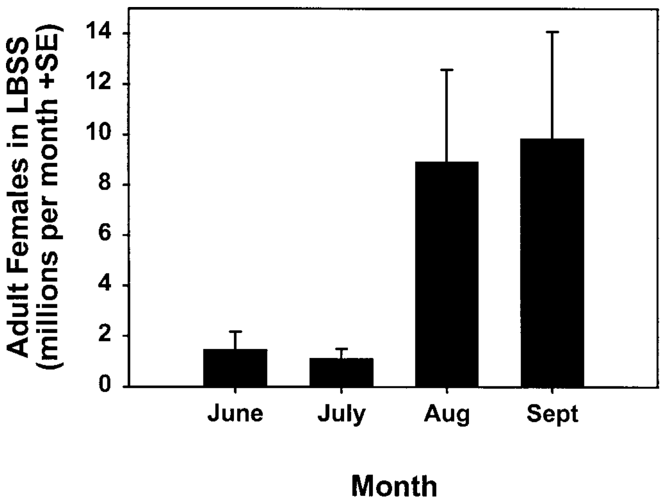

Figure 4. Mean monthly abundance of crabs within the LBSS (millions of females + S.E.) from 11 years (1989-1999) from VIMS trawl survey data and an assumed 3-week residence time.

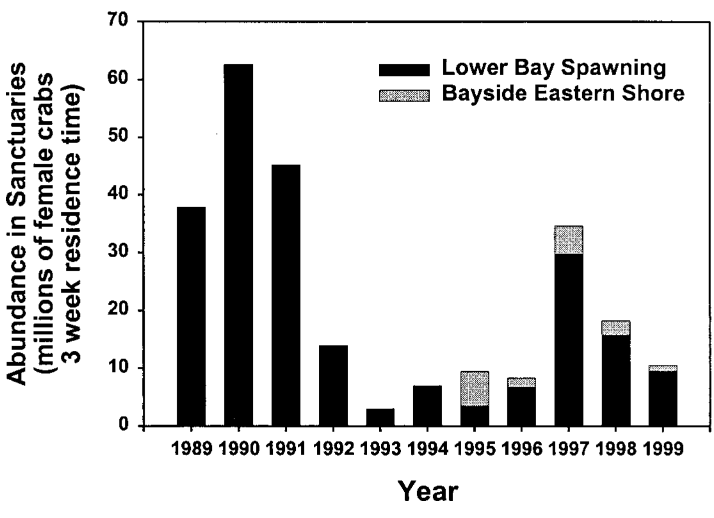

Figure 5. Abundance of adult female crabs within the LBSS (dark shading) during 1989-1999 and the BESS (light shading) during 1995-1999 (the years since establishment of this sanctuary) under the assumption of a 3-week residence time, resulting in the total annual number of crabs protected from fishing pressure in the lower bay 1 June-15 September. Note that the area of the BESS was reduced in 1998.

Female Abundance within Sanctuaries

Adult females enter the lower bay sanctuaries in June and continue to arrive through September (Lipcius et al. 2001). Across the 11 years investigated for the LBSS, crabs were significantly more abundant in August and September than in June and July (Fig. 4; ANOVA, d.f. = 3,39, $F = 2.85$, $P = 0.049$; SNK test). Assuming a residence time of 3 weeks, 3-62 million female crabs were protected by the LBSS (Fig. 5). The BESS protected an additional 1-6 million crabs, which was reduced to 1.0-2.5 million after the BESS was diminished in 1998 (Fig. 5).

Percentage Surviving within Sanctuaries

On average 16 ± 4% (mean ± S.E.) of the potential spawning stock was protected by the sanctuaries, assuming a 3-week residence time (Fig. 6). With 2-week and 4-week residence times, the average percentages of the spawning stock protected by the sanctuaries were 22 ± 5% and 11 ± 3%, respectively (Fig. 6). On average, the percentage of crabs protected was lower during 1991-1994 (mean = 10.4%), when crab abundance was high, than during 1995-1999 (mean = 21.0%), when abundance was low (Fig. 6).

Densities by Geographic Zone

Although the LBSS had highest densities (Fig. 7), there were no significant differences in density by sanctuary or non-sanctuary area (ANOVA, $P > 0.05$). Sample sizes were low, however, particularly in the area removed from the BESS.

Discussion

On average, approximately 16% (range of means = 11-22%) of the Chesapeake Bay's potential spawning stock of the blue crab was protected by a combination of the Lower Bay Spawning Sanctuary (LBSS) and Bayside Eastern Shore Sanctuary (BESS). This estimate is unique in being a first attempt to assess the efficacy of a sanctuary quantitatively. Although the existing blue crab sanctuaries apparently protect a fraction of the potential blue crab spawning stock, is it enough to promote sustainable exploitation?

Miller and Houde (1998) proposed that approximately 28% of the "virgin" spawning stock of the blue crab should be protected for long-term sustainable exploitation. This percentage was derived from a total mortality rate (Z) of 1.275, which was the sum of a 0.9 fishing mortality rate (Miller and Houde 1998) and 0.375 natural mortality rate (Rugolo et al. 1998). On average (i.e., crab residence time of 3 weeks), the spawning sanctuaries only protected an estimated 16% of the potential spawning stock. Furthermore, some small portion of the potential spawning stock was exploited prior to our winter survey, such that our estimates were liberal (i.e., higher than the expected true fraction). Accordingly, we conclude that the spawning sanctuaries at best protect about ¾ (~22%), and at worst about ⅓ (~11%)

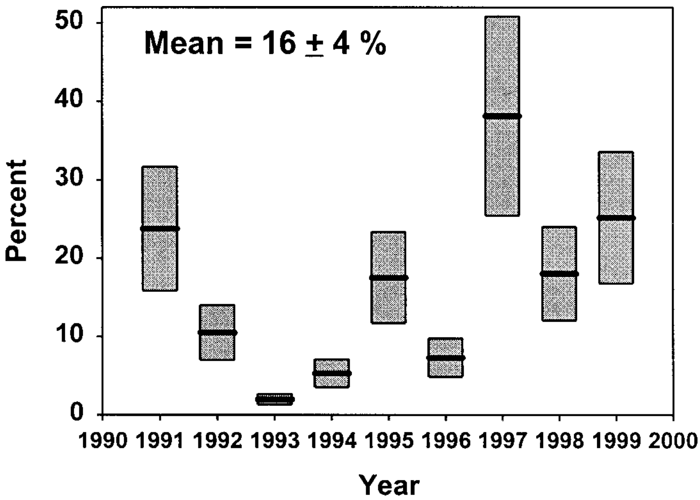

Figure 6. Mean (3-week residence time) annual percentage of adult female crabs in both sanctuaries out of the total number of female crabs baywide on 1 June. Positive and negative extent of error boxes represent the estimates for 2-week and 4-week residence times, respectively.

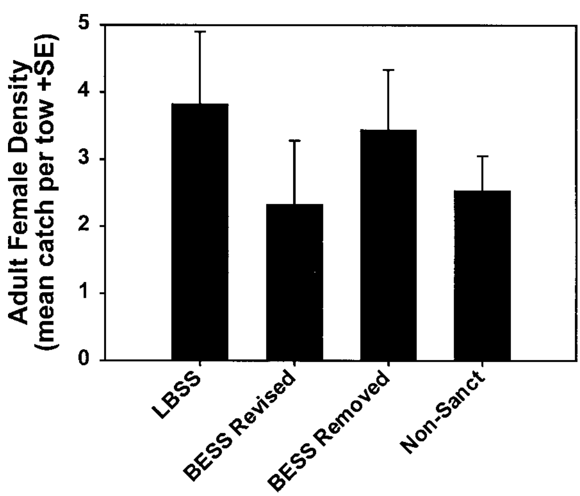

Figure 7. Mean adult female crab densities in the different sanctuary and non-sanctuary areas. LBSS = Lower Bay Spawning Sanctuary, BESS Revised = Bayside Eastern Shore Sanctuary with the current area, BESS Removed = the small pie-shaped area that was removed from the BESS in 1998, and Non-Sanct is the rest of the lower bay that is not included in either sanctuary. Estimates were made from 1989-1999 trawl survey data.

of the estimated sustainable blue crab spawning stock. We therefore recommend a substantial expansion of the lower bay blue crab sanctuaries to arrive at a minimum of 28% protection. Furthermore, we suggest that the sanctuary area added be within the "deepwater corridor" (i.e., channels greater than 13 m) where there are significantly higher densities of adult female crabs than in the shallows (Lipcius et al. 2001). There should also be attention to complementary effort controls that limit displaced effort, which could abrogate any value of expanded sanctuaries. Finally, we recommend modeling of the effect of the expanded sanctuaries upon exploitation rates and spawning stock abundance (e.g., Miller and Houde 1998).

Although the added protection of the BESS was not exceptional, in years when crab abundances were low (e.g., 1995 and 1996) this sanctuary almost doubled the number of crabs protected from exploitation, and was therefore a worthwhile addition to the spawning sanctuary. Furthermore, crab densities within the removed portion of the BESS were among the highest in the lower bay, and the reduction in area of the BESS in 1995 significantly diminished the abundance of protected blue crabs. Hence, we also recommend reinstatement of this portion of the BESS to the spawning sanctuaries.

Given that the lower bay spawning sanctuaries are necessary but not sufficient in preserving a sustainable portion of the spawning stock, the addition of a proposed deepwater migration corridor for adult females could enhance the percentage of protected females in the spawning grounds (Lipcius et al. 2001). This, in addition to an expansion of the existing spawning sanctuary, may protect a sufficient proportion of the blue crab spawning stock, though various problems associated with sanctuaries and reserves, such as redirected effort, need to be addressed (Lipcius, unpubl. manuscript). Temporal expansion of the spawning sanctuaries might also appear to be a desirable management strategy since mating and egg production begin in May and the sanctuaries are not in effect until 1 June.

In sum, we have presented an empirical estimate for the efficacy of spawning sanctuaries for the blue crab in Chesapeake Bay which indicates that the existing sanctuaries do not protect a sufficient fraction of the spawning stock for sustainable exploitation. We suggest the addition of a deepwater corridor coupled to the spawning sanctuaries in the lower bay to selectively conserve female crabs migrating to or residing in the lower bay spawning grounds (Lipcius et al. 2001). If fishing effort is not substantially redirected, an expanded sanctuary would promote a more stable and abundant spawning stock interannually (Lipcius and others, unpubl. manuscript). Based on our analyses, an expansion of the existing spawning sanctuary seems necessary to conserve the blue crab spawning stock in Chesapeake Bay.

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