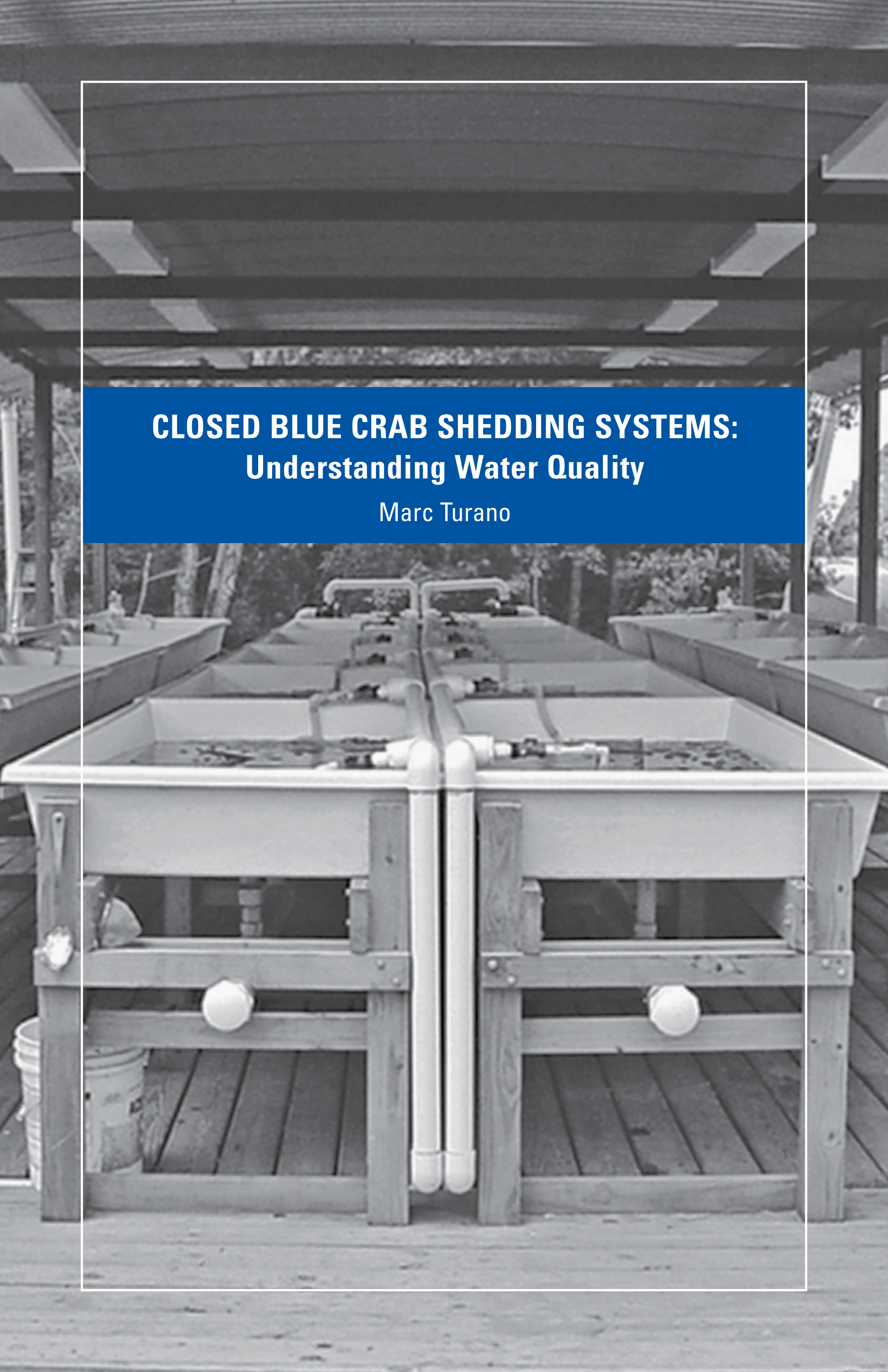
# CLOSED BLUE CRAB SHEDDING SYSTEMS: Understanding Water Quality

Marc Turano



## Glossary

| | |
|---|---|
| DO | Dissolved oxygen |
| $NH_3^-$ | Un-ionized ammonia |
| $NH_4^+$ | Ionized ammonia |
| $NO_2^-$ | Nitrite |
| $NO_3^-$ | Nitrate |
| TAN | Total ammonia nitrogen |

## About the Author

Marc Turano is North Carolina Sea Grant's mariculture and blue crab specialist. He is also the coordinator for the N.C. Blue Crab Research Program, where he helps potential applicants with grant proposals and project design, as well as monitors ongoing blue crab research.

Turano received his Ph.D. in zoology from North Carolina State University. He also holds a bachelor's in marine biology from the University of North Carolina at Wilmington and a master's in mariculture from Texas A&M University-Corpus Christi.

## About the N.C. Blue Crab Research Program

The N.C. Blue Crab Research Program (BCRP) is funded by the N.C. General Assembly and administered by North Carolina Sea Grant. The BCRP encourages innovative proposals that will improve, protect and restore North Carolina's blue crab resources. Where appropriate, BCRP seeks to partner commercial and recreational fishers, and persons in the seafood industry with academic researchers to ensure useful, well-documented results.

A list of potential research topics and a list of Sea Grant and N.C. Division of Marine Fisheries contacts, as well as ongoing and previous BCRP projects, are available at *www.ncseagrant.org.* Under "Funding Opportunities," select the Blue Crab link. Information is also available from North Carolina Sea Grant offices in Raleigh, Manteo, Morehead City and Wilmington.

## Photos

Ken Blevins and Marc Turano

## Crab Art

Duane Raver

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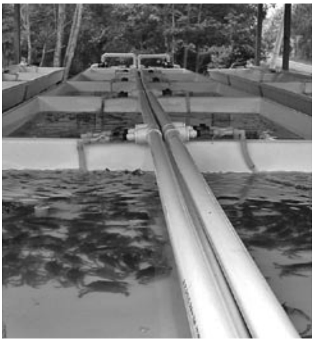


The soft crab industry in North Carolina is a significant part of the state's blue crab fishery. From 2001 to 2005, the average annual landings for peeler crabs and soft crabs in the state were 1.6 million pounds with a total value of $4.8 million, according to the N.C. Division of Marine Fisheries. In 2007, there are more than 300 licensed crab shedders in North Carolina operating more than 5,500 shedding tanks. These operators either purchase peeler crabs for shedding, or harvest and shed their own crabs. In 2002, North Carolina Sea Grant researchers David Eggleston and Juan Chavez reported mortalities in 11 soft shedding systems that ranged from 10 to 30 percent. Because soft crabs are worth up to seven times the value of hard crabs, such losses can significantly reduce profitability. Further, blue crabs in North Carolina are listed as a species of concern and excessive mortalities experienced in the soft crab fishery represent an inefficient component of the fishery.

Three crab shedding techniques are used in North Carolina: floating trays, onshore flow-through systems and closed recirculating systems. Most operations in the state utilize the onshore flow-through system design, which requires the least maintenance. However, this design relies on the availability of a consistent supply of clean water, which can fluctuate with changing environmental conditions. Closed shedding systems minimize fluctuations in environmental conditions and allow crab shedding operations to move to less expensive inland areas. These systems recycle water through a series of filters to minimize the need for new water. However, closed shedding operations have not increased in North Carolina. This is likely due to an incomplete understanding of the techniques required to manage these systems.

Closed shedding systems require proper design and maintenance. Operators of these systems must maintain sufficient water quality for crabs to survive. Parameters, such as total ammonia nitrogen (TAN), nitrite ($NO_2^-$), nitrate ($NO_3^-$), salinity and—most importantly—dissolved oxygen (DO), should be tested regularly, and more frequently during peak shedding seasons. To run closed shedding systems successfully, an operator must have a thorough understanding of how these water quality variables interact.

## The Good and the Bad

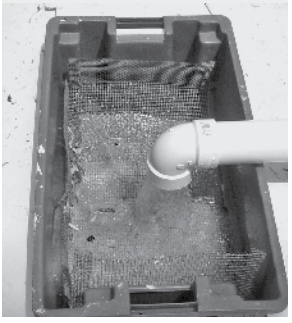
The closed system, like other shedding systems, has both advantages and disadvantages.

### Advantages

The closed system allows for increased control over the shedding environment —the water. In a closed system, salinity and temperature can be regulated, minimizing potential problems with excessive rainfall or drought. Additionally, in areas where tidal movements caused by wind patterns can completely remove available water, closed systems can continue to operate. Siltation problems, such as muddy water, are minimized because a constant supply of clean water is not necessary. Another important advantage is the flexibility in locating the system. Without the need for a water source nearby, closed systems can be constructed away from expensive waterfront property.

### Disadvantages

Closed systems are more complex than flow-through systems. Water must be filtered so that recycled water does not degrade the environment in the tanks and harm the shedding crabs.



Depending on the level of sophistication, closed systems can be costly, particularly during the start-up phase. Filters add to the expenditures for tanks, pumps and plumbing supplies used in flow-through systems. Closed systems also require more maintenance. Regular filter maintenance and water quality monitoring are required to ensure optimal holding conditions that minimize stress on the crabs. Closed systems do not offer the dilution factor of flow-through systems. If a closed system experiences a sudden bout of poor water quality (for example, a spike in ammonia levels), the only method of rapid removal is with water exchange.

Another disadvantage of closed systems is the inability to fill the tanks with water and immediately stock them with crabs. Closed systems need to be started earlier in the season because the system needs to be "cycled" to establish a population of healthy bacteria. Furthermore, if a shedding operation continues throughout the hard crabbing season, the bacteria established at start-up must be fed to sustain sufficient levels for periodic stocking of peelers.

## When is a Closed System Appropriate?

Crab shedding operators must consider several factors when deciding if a closed system is the most efficient method of shedding crabs. Factors to consider include:

- Location
- Level of production/risk
- Cost

***Location*** is one of the most important factors when considering a closed system. Often, an operator does not have a choice in the location for a commercial operation. Consider the source of water at the chosen location. Some shedding operations use well water and add commercially available sea salt, while others haul or pump water from nearby rivers, creeks or estuaries. The water source should be chosen based on quantity, quality and cost. Although large volumes of water are not necessary for a closed system, it is beneficial to have access to a good water source for emergencies, as well as for filling and/or flushing the system.

The water for a closed shedding system should have certain characteristics including balanced pH and alkalinity. It also should be free of toxic compounds such as heavy metals and pesticides. Although these water quality variables can be manipulated with chemicals, it is best to use "good" water at the beginning to minimize costly chemical additions.

Another consideration is the desired ***level of production/risk.*** Operators must manage all systems to ensure low crab mortality. Removal of dead and newly molted crabs are required for the system to remain operable and profitable. However, closed systems require a greater degree of management. Ideally, DO levels should be checked daily, and all other parameters—TAN, $NO_2^-$, $NO_3^-$, salinity and pH—weekly.

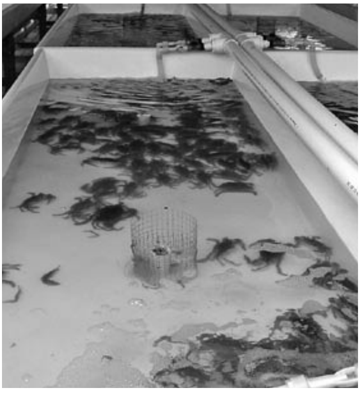
Although there is no exact schedule, water quality monitoring should increase during the peak season. During times of lower stocking densities, monitoring can be reduced. Response time is a key component when responding to a water quality problem. The crabs cannot move as they would to escape poor conditions in the wild. Routine water quality sampling and recording of these measurements can significantly reduce unexpected changes in water quality.

For operators, experience is the best teacher for managing closed systems. For newcomers, an appropriate design is key, along with following management recommendations (for example, maintaining water quality). However, because shedding crabs remains somewhat of an art, the more experienced an operator becomes, the easier the system is to manage. Closed systems require additional time for water quality maintenance, which should be considered when deciding which type of system to construct.

In many cases, *cost* is the limiting factor when operators consider what type of shedding system to construct. Unfortunately, budget constraints often result in poorly built and ineffective shedding systems.

When designing a system, operators should identify the maximum number of shedding tanks to install—immediately and in the future. This is typically accomplished through the business plan, which accounts for the number of crabs that need to be produced, along with market demand/pricing and overhead. Purchase pumps and filters that are capable of handling the future capacity. Oversized pumps and filters will not harm a shedding system and will minimize future costs of upgrades. Conversely, underestimating the size of these components can undermine the success of a shedding operation.

If a closed system is appropriate for a specific location, proper design is essential. Closed shedding systems utilize the same shedding trays, pumps and piping as flow-through systems. The difference is in the filters. Before designing appropriate filters for a closed shedding system, operators must understand interactions in water quality that occur in these systems—and, in turn, the purpose for the various filtering components. The remainder of this document will focus on the specific water quality parameters that must be monitored in closed shedding systems for proper system maintenance. These include: DO, temperature, nitrogenous wastes (TAN, $NO_2^-$, $NO_3^-$), pH and alkalinity.



## Water Quality Interactions

### Dissolved Oxygen (DO)

The most important water quality parameter in closed shedding systems is dissolved oxygen (DO). Proper oxygen levels must be maintained in a shedding system to provide an optimal environment for crab molting and survival, as well as biological filtration.

DO levels should be maintained at or above 5 parts per million (ppm) or 5 milligrams per liter (mg/l) in the shedding trays. Oxygen levels can be affected by salinity, temperature and density of crabs stocked. As temperature, salinity and crab density increase in a shedding system, the ability of that water to hold oxygen decreases. DO levels will be most problematic in full-strength seawater systems during the warmer summer months.

Measuring DO is simple using various test kits. However, compared with a DO meter, test kits can be less accurate, difficult to use and cumbersome when multiple measurements are needed. Operators are encouraged to purchase a DO meter. They range in price, depending on quality and additional measurements, such as temperature, pH and salinity. Select a meter that can withstand frequent use and exposure to a harsh environment.

Oxygen levels must be checked often and in multiple places. Check the levels daily to ensure the system is operating properly. During periods of very high stocking densities (several hundred crabs per tray), check DO levels multiple times throughout the day. Oxygen levels should be monitored in the trays as well as at the sump or biofilter. Because the biofilter is "alive," the bacteria need sufficient oxygen to survive. Dissolved oxygen levels should be at least 5 ppm in the water leaving the tanks and entering the biofilter. DO levels above 5 ppm are optimal for shedding and crab survival.

### Temperature

Because peeler crabs do not begin to appear in crab harvests until the water warms to about 65 F, shedding systems benefit from being maintained above this temperature. Although an "optimal" temperature for crab shedding has not been determined, most closed shedding operations maintain water temperature between 70 and 80 F. Further, temperature plays an important role in TAN toxicity *(see the TAN section).*

Consider whether to house the system in a closed building. Temperature can be kept stable for the entire shedding season in indoor systems. The ability to warm water in the spring allows the operator to start earlier stocking of peeler crabs and provides a more consistent temperature throughout the season. When the system is fully enclosed, heating or cooling the air in the room will adjust the water temperature. Outdoor shedding systems are typically not maintained for temperature due to the costs associated with heating or cooling the water.

### Nitrogenous Wastes and the Nitrification Process

Nitrogenous wastes—waste products with nitrogen—originate from a number of sources. These include crab excretion and osmoregulation (how crabs maintain their blood chemistry), and debris materials from harvest. The process of nitrification occurs in the biofilter, where nitrogenous wastes are converted into nontoxic forms. Ammonia is produced mainly from crab waste and is converted into a relatively nontoxic form of nitrogen, nitrate ($NO_3^-$). *Fig. 1* shows two chemical equations for the nitrification process.

Equation 1:
$$\underset{\text{(Ammonium)}}{2NH_4^+} + \underset{\text{(Oxygen)}}{3O_2} \longrightarrow \underset{\text{(Nitrite)}}{2NO_2^-} + \underset{\text{(Water)}}{2H_2O}$$

Equation 2:
$$\underset{\text{(Nitrite)}}{2NO_2^-} + \underset{\text{(Oxygen)}}{O_2} \longrightarrow \underset{\text{(Nitrate)}}{2NO_3^-}$$

***Fig. 1: Chemical reactions in nitrification***

Because oxygen is essential to this process, ensuring that DO levels in the shedding trays are maintained at 5 ppm or greater will result in sufficient DO to the biofilter.

#### *Total Ammonia Nitrogen (TAN)*

Ammonia is a form of nitrogen. TAN is the combination of two forms of ammonia—un-ionized ($NH_3^-$) and ionized ($NH_4^+$). $NH_3^-$, the un-ionized form, is toxic to crabs at low levels, while $NH_4^+$ is relatively nontoxic. Both forms of ammonia are present in closed shedding systems. However, those amounts are dependent on temperature and pH. Because most test kits provide measurements as TAN, the operator must know the temperature and pH to calculate the level of toxic ammonia.

Ammonia released by crabs accumulates in a shedding system. Other sources include the breakdown of crab waste (feces) and other nitrogen-rich materials, such as soil and debris from harvest. Blue crabs do not rid themselves of ammonia by urinating. Rather, they release ammonia through their gills to maintain proper salt and water balance. As ammonia builds in the shedding system, crabs cannot continue to release ammonia, thereby accumulating it within their bodies. Too much ammonia in the crabs can lead to tissue toxicity and death.

Ammonia is removed from closed shedding systems by the nitrification process in the biofilter, or by flushing. Biological filters, known as “biofilters,” are chambers that house substrate (plastic beads, oyster shell, sand, etc.) on which bacteria can grow. These bacteria will "nitrify," or convert the toxic ammonia into its eventual form, $NO_3^-$ *(refer to the equations in Fig. 1).* For the biofilter to function properly:

- The filter must be sized appropriately (with sufficient substrate material).
- Sufficient water flow from the tanks must be provided to the filter.
- Water flowing to the filter must be of the appropriate water quality *(see System Maintenance section).*

Ammonia is typically measured with a test kit. Be sure the appropriate test kit is used, because saltwater and freshwater kits use different reagents. Most closed systems operate at low salinity—5 to 10 parts per thousand (ppt)—where freshwater test kits can be used. Closed systems operating on greater than 10 ppt will require a saltwater test kit. Also, each test kit may be different in the resulting test value, with most reporting TAN rather than solely the toxic form of ammonia, $NH_3^-$. This discrepancy can lead to some confusion because crabs can withstand high levels of TAN but not high levels of $NH_3^-$.

***Table 1: Un-ionized ammonia factors***

| **Temperature** | | **pH** | | | | | |
|---|---|---|---|---|---|---|---|
| **°C** | **°F** | **6.5** | **7.0** | **7.5** | **8.0** | **8.5** | **9.0** |
| 10.0 | 50.0 | 0.0006 | 0.0019 | 0.0058 | 0.1082 | 0.0556 | 0.1567 |
| 15.0 | 59.0 | 0.0009 | 0.0027 | 0.0086 | 0.0268 | 0.0801 | 0.2159 |
| 20.0 | 68.0 | 0.0001 | 0.0040 | 0.0124 | 0.0383 | 0.1118 | 0.2847 |
| 25.0 | 77.0 | 0.0002 | 0.0059 | 0.0175 | 0.0532 | 0.1510 | 0.3598 |
| 30.0 | 86.0 | 0.0026 | 0.0081 | 0.0251 | 0.0751 | 0.2045 | 0.4482 |

*Standard methods for the examination of water and wastewater.* American Public Health Association (APHA), American Water Works Association and Water Pollution Control Federation. 15th ed. APHA, New York. 1980.

Changes in pH and/or temperature will result in changes between the percent of both toxic and nontoxic forms of ammonia. *Table 1* displays the relationship between pH, temperature and the amount of un-ionized ammonia. As temperature and pH increase, the amount of un-ionized (toxic) ammonia increases. *Fig. 2* is an example of calculating $NH_3^-$ from TAN. To calculate $NH_3^-$ from TAN, find the pH and temperature in the table of associated values usually found with the test kit to get an un-ionized ammonia factor *(see Table 1)*. Then multiply the factor by the ppm of TAN.

Example:

- pH = 8.0
- Temperature = 77 F
- TAN = 1.5 ppm

Using *Table 1*, locate the factor that intersects at a pH of 8.0 and temperature of 77 F: **0.0532**

Next, multiply 0.0532 x 1.5 ppm = 0.0798 ppm $NH_3^-$.

***Fig. 2: Example of calculating un-ionized ammonia ($NH_3^-$) in Total Ammonia Nitrogen (TAN)***

## *Nitrite ($NO_2^-$)*

A by-product in the conversion of ammonia, $NO_2^-$ is toxic to crabs at low levels and should be kept below 0.5 to 1.0 ppm. Excessive nitrite can suffocate crabs because it decreases the ability of crab blood to transport oxygen. Like ammonia, $NO_2^-$ is removed through biofiltration and/or flushing. Sufficient oxygen levels are required in the biofilter as well as in the shedding tanks. The equations in *Fig. 1* show that oxygen is required to convert ammonia to $NO_3^-$. Some shedding systems have problematic $NO_2^-$ levels, a condition likely due to insufficient oxygen to convert ammonia to $NO_3^-$.

In systems using lower salinity waters, increasing the salinity can reduce some of the negative effects of $NO_2^-$ toxicity. In crab blood, $NO_2^-$ attaches to hemocyanin, the oxygen-carrying molecule in blood. $NO_2^-$ takes up sites on the hemocyanin molecule, leaving less room for oxygen to attach. Adding salt (NaCl) increases the amount of chloride ions ($Cl^-$) in the water. The additional $Cl^-$ outcompetes the $NO_2^-$ on the gills of the crab and prevents $NO_2^-$ from binding to hemocyanin. Maintaining salinity levels at 10 ppt and above may provide crabs some protection from $NO_2^-$ toxicity.

$NO_2^-$ is managed similarly to ammonia—weekly measurements with more frequent measurements during peak loading. Simple test kits are available and no calculations are necessary to obtain the level of $NO_2^-$.

## *Nitrate ($NO_3^-$)*

The final product of nitrification is nitrate, or $NO_3^-$. This product is generally not toxic to crabs, unless it exceeds 500 ppm. As ammonia is broken down, $NO_3^-$ levels will gradually increase. Generally, an $NO_3^-$ “spike” will not be observed.

Once $NO_3^-$ levels increase above 500 ppm, operators must change the water to remove $NO_3^-$ from the system. $NO_3^-$ can be converted to nitrogen gas, but this only occurs in areas without oxygen, which is not beneficial to shedding systems. Typically, monthly or bi-monthly water exchanges, depending on loading, will be sufficient to keep $NO_3^-$ levels in check. During a water exchange, a portion of the water is drained from the system and replaced with new water.

$NO_3^-$ levels can be tested using test kits similar to that for $NO_2^-$. At the start, testing should occur twice per month. After several months of testing, shedding system operators should be able to determine if the water exchanges are sufficient to remove $NO_3^-$ and minimize future testing.

### pH

"Per hydronium ion," or pH, measures the acidity or alkalinity in the water. The measurement is reported on a scale of 1 (acidic) to 14 (basic or alkaline). Water with a pH of 7.0 is considered neutral. The pH value can vary with the source of water. Full-strength seawater—32 ppt—usually has a pH of 8.2. Water sampled near creeks or ditches could have a pH below 7.0 because of the increase in acids originating from the decomposition of grass, leaves and dead organisms.

The measure of pH in a shedding system is important for several reasons. First, crabs must try to match their internal pH with that of the environment. Second, pH is one of the determining factors in how much ammonia becomes toxic. *Table 1* shows that increases in pH and temperature result in a higher percentage of ammonia in the toxic form. Lastly, a proper pH is necessary for bacteria to thrive in the biological filter.

The pH in a shedding system should be maintained between 6.8 and 8.2. Typically, pH decreases in a system over time. This decrease is the result of nitrification and crab respiration, both of which increase carbon dioxide ($CO_2$). $CO_2$ is a weak acid. Therefore, an increase in $CO_2$ leads to more acid in the water and a decrease in pH.

In many closed shedding systems, adding buffering material such as oyster shell can prevent decreases in pH. Oyster shell is composed of calcium carbonate, a compound with a basic pH (>7.0). As the pH of the water decreases, oyster shells dissolve, and calcium carbonate is released. The calcium carbonate acts to buffer the low pH, increasing the pH of the system. Periodic flushing also helps to remove some of the waste in the system, preventing a decrease in pH.

Monitoring pH is simple with a test kit or pH meter. It should be monitored weekly, and more often during peak loading periods.

### Alkalinity

Alkalinity, also referred to as buffering capacity, is the ability of water to resist an increase or decrease in pH. Proper alkalinity helps prevent large changes in pH. The nitrification process produces acid that decreases pH. The presence of basic materials—those with a higher pH, such as oyster shell—in the system can provide a buffer to maintain a higher pH level. Commercial shedding operations should include oyster shell or similar material in the biofilter or other parts of the system to help increase alkalinity. Alkalinity should be measured at the start of a shedding operation and periodically throughout the season. Alkalinity levels of 100 ppm or greater are preferred.

## Water Quality Management in Closed Shedding Systems

### System Start-up

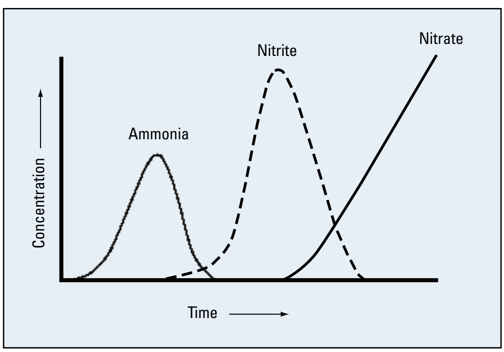



*Fig. 3: Changes in the Concentration of Ammonia, Nitrite and Nitrate Over Time*

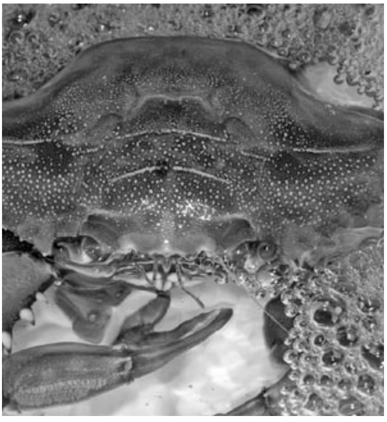
One of the disadvantages of using a closed shedding system is that it cannot be filled and stocked immediately, as with a flow-through system. Because bacteria need to establish themselves in the biofilter, new shedding systems should be cycled for four to eight weeks, depending on temperature, before adding crabs.

*Fig. 3* is a typical example of the nitrification process during start-up. Ammonia accumulates in the system from waste by-products of the initial stocking organisms. Simultaneously, *Nitrosomonas sp.*, the bacteria responsible for converting ammonia to $NO_2^-$, begins to multiply. Once a sufficient colony of *Nitrosomonas sp.* is established, ammonia decreases, and $NO_2^-$ builds. Along with the decrease in ammonia, *Nitrobacter sp.*, the bacteria responsible for converting $NO_2^-$ to $NO_3^-$, also begins to multiply, causing a decrease in $NO_2^-$. The resulting product is $NO_3^-$, which gradually builds in the system, and is removed through periodical flushing.

To start a new system, place hard shell jimmy crabs and/or other species that are tolerant of varying water quality into the trays and feed them daily. Bacteria present in the fill water and introduced by the animals will "seed" the biofilter bed with nitrifying bacteria. Waste from feeding the crabs and/or fish provide the raw material for bacteria to begin converting ammonia into $NO_2^-$ and then $NO_3^-$. Once the $NO_2^-$ spike declines, it is safe to begin stocking peeler crabs. The overall process varies with temperature and salinity, but generally ranges from four to eight weeks. Add peelers gradually to avoid shocking the system, as the bacteria bed will continue to grow with increases in crab density.

## System Maintenance

Once closed systems are cycled with bacteria established in the biofilter, they must be maintained at a consistent stocking rate. Following a peeler-crab run, a shedding system typically has few crabs stocked. To prepare the system for another peeler run, stock and feed hard crabs or other species during the down period. The biofilter in a closed system must be fed continuously to be properly maintained and ready for stocking peelers. "Shock loading," or adding large numbers of peelers (without maintaining some load on the system) in a short period of time, should be avoided.



Conduct water exchanges monthly or once every other week. Ideally, operators should replace 25 percent of the system water with new water during an exchange. Promptly removing settled solids in the system also will help maintain good water quality. Finally, operators should ensure algae does not accumulate in, or on, the biofilter media. Algae in the biofilter will reduce the filter's capacity to convert ammonia into $NO_3^-$ because the algae out-compete the bacteria for space on the media. *Table 2* shows optimal parameters for crab shedding in a closed shedding system.

*Table 2: Optimal Parameters for Crab Shedding in a Closed System*

| Parameter | Measurement |
|---|---|
| DO | 5 ppm in trays |
| pH | 6.8 to 8.2 |
| Toxic Ammonia | 0.5 to 1.0 ppm |
| Nitrite | 0.5 to 1.0 ppm |
| Salinity | Maintain within 5 ppt of capture water |
| Alkalinity | >80 ppm |

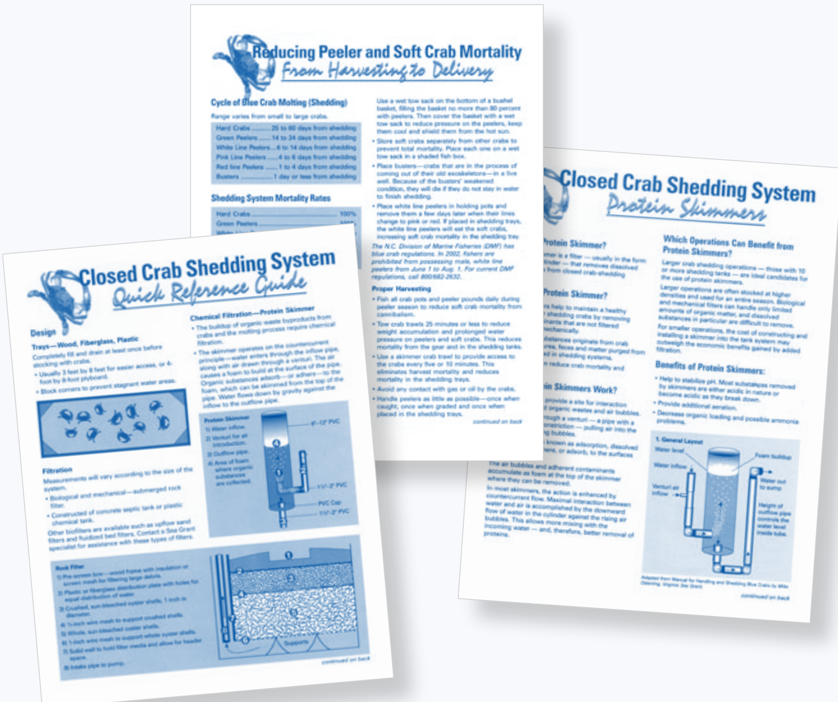
The parameters listed here are "optimal" but may be difficult to maintain at peak loading densities. However, maintaining levels close to these will help ensure crab survival. Individual measurements should be taken on a regular basis and recorded in a log. Temperature and dissolved oxygen levels should be monitored daily, while TAN, $NO_2^-$, $NO_3^-$ and pH should be monitored weekly. Salinity and alkalinity testing should be performed at initial setup and after each water exchange. Perform additional testing if there is an increase in observed mortalities, abnormal crab behavior, or if the color and/or smell of the system water changes.

## Summary

Closed shedding systems have a place within North Carolina's blue crab fishery if fishers work to understand how to maintain water quality. The advantage of moving away from waterfront property without sacrificing shedding success makes this system design attractive. Key points to remember if you decide to construct a system are:

- Design the system for the maximum number of tanks to be used. Consider not only current, but also future growth plans. Tanks can always be added, but purchasing larger pumps and/or filters later will substantially reduce profits.
- Retain additional water in the system. More is better when it comes to water. Oversize the sump to increase overall water quality.
- Water chemistry must be understood to operate any closed crab shedding system, however designed. Monitor dissolved oxygen, nitrite and ammonia levels more aggressively during the active season. Keep a log for water quality maintenance records to help identify problems before and after they occur.
- Stock the system slowly. New shedding systems require a lead time of four to six weeks before adding crabs. "Shock loading" of peeler crabs almost certainly causes unnecessary crab deaths.

## Additional References




For more information on soft shell crabs or shedding systems, refer to the following publications.


- *Reducing Peeler and Soft Crab Mortality: From Harvesting to Delivery.* Wayne Wescott. North Carolina Sea Grant Publication #: UNC-SG-02-02
- *Closed Crab Shedding System: Protein Skimmers.* Marc Turano. North Carolina Sea Grant Publication #: UNC-SG-03-06
- *Closed Crab Shedding System: Quick Reference Guide.* Marc Turano. North Carolina Sea Grant Publication #: UNC-SG-02-01
- *Design of Recirculating Blue Crab Shedding Systems.* Ronald Malone and Daniel Burden. Louisiana Sea Grant Publication #: LSU-T-88-003-C2
- *Blue Crab Shedding Systems: Water Quality Concerns.* Harriet Perry. Maryland Sea Grant Publication #: MASGC-G-85-003-C2
- *Manual for Handling and Shedding Blue Crabs (Callinectes sapidus).* Michael Oesterling. Virginia Sea Grant Publication #: VSGCP-H-88-003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