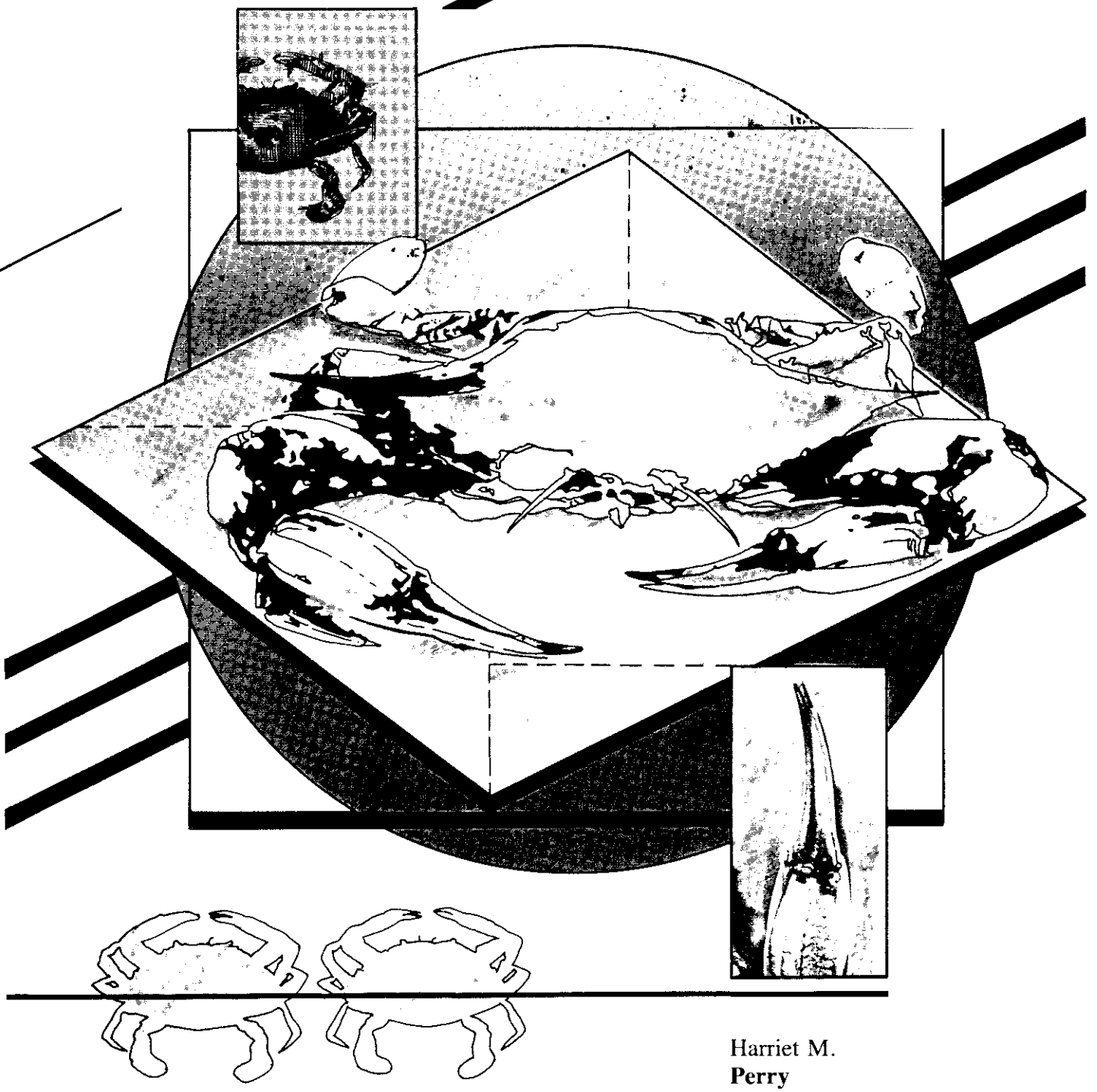
Proceedings of the National Symposium on the Soft-Shelled Blue Crab Fishery



Harriet M. **Perry**
Ronald F. **Malone**
Editors

NATIONAL SYMPOSIUM
ON THE SOFT-SHELLED BLUE CRAB FISHERY

Edited by

Harriet M. Perry and Ronald F. Malone

Sponsored by

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and
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GULF COAST RESEARCH LABORATORY
J. L. Scott Marine Education Center
Biloxi Campus

February 12-13, 1985

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DEDICATION

We dedicate this symposium to

W. A. VAN ENGEL

of the Virginia Institute of Marine Science

Fellow scientist, teacher and, most of all, friend

CONTENTS

CONTENTS (Continued)

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985.

WELCOME

DR JAMES I. JONES
Director, Mississippi-Alabama Sea Grant Consortium

I welcome you on behalf of the Mississippi-Alabama Sea Grant Consortium and the Louisiana Sea Grant College Program. This symposium is sponsored by the Southeast Marine Advisory Service network and the Mid-Atlantic Advisory Service network of Sea Grant. All of us are very pleased that you could be here today.

The concept of the National Symposium for soft shell blue crab is one that has been knocking around for some time. It took the combined efforts of the organizations I just noted plus the specific efforts of several individuals, most of whom are noted by their presence and their work in this field. You'll be seeing them off and on throughout the day. I do believe without Bill DuPaul, Harriet Perry and Bill Hoskings ramrodding this, it probably wouldn't have happened. I think it's a very great opportunity for a diverse group of persons from around the country to come together. We have scientists, economists, and the private sector. I think we have all the elements we would like to have involved in this sort of symposium. I believe sincerely and honestly that the results of this symposium will lead to a number of new initiatives; both in the public and private sectors. If that is indeed the case, then we will have accomplished our goals in establishing this national symposium.

There are a few other persons who need to be mentioned. We are here through the cooperation of Dr. Harold Howse of the Gulf Coast Research Laboratory, and Mr. Gerald Corcoran, Curator of the J. L. Scott Marine Education Center of the Gulf Coast Research Laboratory. I would like to note that we have some participants from Mexico, and we are pleased that you foreign visitors could be with us today. Also, I would like to recognize Mr. Cultus Pearson, a commercial fisherman from Lacombe, LA, who has been truly cooperative with the investigators involved in organizing this symposium and with our Sea Grant investigators working on blue crab research projects over the past six or so years. And finally, this symposium is dedicated to Willard A. Van Engel, of the Virginia Institute of Marine Science, who is retiring this June. He is the leading blue crab biologist in the United States and we are honored to have him here with us at this time.

I declare this symposium open.

INTRODUCTORY REMARKS

DR. WILLIAM DuPAUL
Virginia Institute of Marine Science

On behalf of the Mid-Atlantic Advisory Service Network, I welcome you to the first national symposium on the soft crab fishery of the United States. This symposium is an outgrowth of a series of regional workshops held over the past several years addressing both problems and advancements in the industry. Sea Grant has always had an active program in either research or advisory efforts to enhance the industry and to pass on technological advancements. We have seen considerable growth in the soft crab fishery as a result of Sea Grant activities.

The soft crab fishery has been a success story as far as Sea Grant is concerned. Sea Grant, however, is not the only agency responsible for development of the fishery. State resource agencies, research institutions and universities, and the fishing community have played a vital role in this "success story."

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985, 1–12.

PHYSIOLOGY OF THE BLUE CRAB *CALLINECTES SAPIDUS* RATHBUN DURING A MOLT

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INTRODUCTION

As a student in the laboratory of L. M. Passano (1960), I read many of the classic papers on the subject of blue crab molting although I, personally, did not work on it. Later, learning about gas exchange and metabolism in the blue crab (Mangum and Weiland 1975), the casual observations in those papers kept returning to my mind—molting should not be possible.

Long before this study, it was known that blue crabs are not very good anaerobes (Carpenter and Cargo 1957). Like many decapod crustaceans, they are more dependent on their oxygen (O_2) transport system than most other groups of animals. In the temperature range that prevails between the spring and the fall, the hemocyanin (Hc) in the blood of a blue crab transports more than 95% of the O_2 consumed by the tissues and almost none is carried in the free form. This is true because the crab is locked up in a gas-impermeable box that it uses as a skeleton, which does not exist in the same form outside of arthropods. When the O_2 transport system fails, which it sometimes does, the crab cannot sustain life for even an hour by an entirely O_2-independent metabolism.

Many of the casual observations in those old papers suggested that the system does fail during a molt, a time when the metabolic demands should be greater, not smaller, than usual. Specifically, the uptake of water, which lets the crab split the old exoskeleton, dilutes the Hc in the blood by about one-half. Our data show that the Hc levels fall far more than that, to about one-fifth of the intermolt value, which implicates a change in net synthesis or degradation. To compound the problem, a number of the factors that determine the amount of oxygen the blood transports also change. Acid-base balance and blood calcium (Ca^{+2}) are perturbed; both hydrogen (H^+) and Ca^{+2} combine with the Hc molecule and directly influence its O_2 binding. Shedding the old exoskeleton appears to require taxing motor activities and high levels of motor performance which, in turn, require input from anaerobic metabolism (McMahon 1981). Additionally, a number of investigators believe that the ventilatory appendage cannot function because it is soft, which should inhibit O_2 uptake at the gill (e.g., Lewis and Haefner 1976). Both the exercise and the inhibition of ventilation should activate anaerobic glycolysis, which terminates in lactic acid. Lactate also combines with the Hc molecule and directly determines its O_2 binding (Truchot 1980).

If the system normally fueling metabolism does not work and if the alternative mode of metabolism is not sufficient to sustain life, then how is life possible during a molt? To find out, I persuaded several experts on various aspects of crustacean physiology to join me for a coordinated study of molting in the blue crab *Callinectes sapidus* Rathbun; the results summarized below were obtained by all of us. Because the processes of gas exchange and acid-base regulation are often intimately interwoven with those of mineral and water metabolism, our studies included those areas as well.

MATERIALS AND METHODS

Gas Exchange, Transport and Acid-Base Balance

The information in the literature on total O_2 uptake was contradictory so it was necessary to show that the blue crab behaves like other species, which it does. There was no clear increase in O_2 uptake during premolt, which had been reported for other species. But the rate clearly went up in early postmolt and then gradually returned to the intermolt value (Figure 1). At the tissue level an increase could be seen in the epidermis during premolt as well as postmolt, reflecting the onset of metabolic activity during manufacture of the new skeleton (Figure 1). However, the epidermis is such a small fraction of the total biomass that the change could

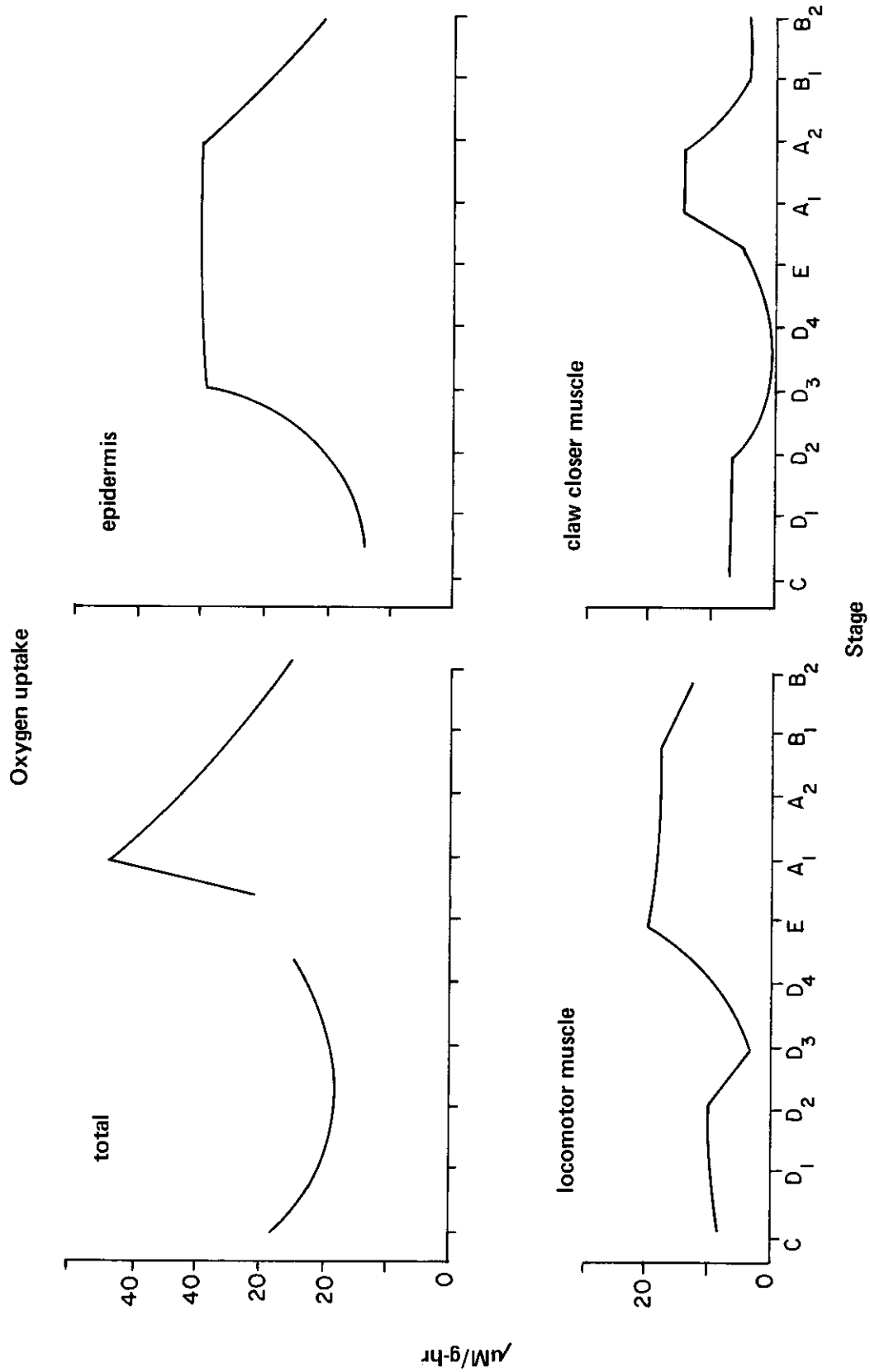

Figure 1. Changes in O_2 uptake in whole animals and isolated tissues during the intermolt cycle (24 to 26°C, 35 ppt, ambient PO_2 100 to 159 mm Hg). (Data from Mangum et al. 1985).

not be detected in an intact animal. As shown by Mauro and Mangum (1982), total O_2 uptake was dominated by the locomotor muscle, which comprises about two-thirds of total biomass. In the present study, the interest was in the increase in O_2 uptake during the postmolt (Figure 1).

Blood PO_2 rises during premolt as the animal reduces its locomotor activity (Figure 2). At the same time blood pH rises, which is very important because it effectively loads the blood with HCO_3^-, which will serve as a buffer against the metabolic acids produced later during exuviation. During this period there may be a small increase in ventilation, which would contribute to the rise in blood pH by blowing off more CO_2, but this is not shown in Figure 3 because it was not significant and it appeared to be too small to explain the change in full. During busting blood pressure begins to rise as the animal takes up water (Figure 3). During actual exuviation blood pressure is 5.5 times that during intermolt. It is this pressure that structurally substitutes for the loss of the hard exoskeleton and allows the animal to perform the muscular movements necessary to shed the exoskeleton. In essence the animal reverts to a more primitive form of support, the hydrostatic skeleton.

Measuring ventilation in crabs involves putting a mask over the excurrent openings of the branchial chambers. The mask prevents exuviation because the sutures can not open; therefore, we were unable to measure ventilation during actual exuviation. Ventilation appeared to cease momentarily when the scaphognathite was being pulled out. We were able to measure ventilation at all other times. It was very clear that flow does not decrease much less cease during busting (Figure 3). Blood PO_2 increases at the gill and decreases at the tissues (see Figure 2), which could be due to a decrease in blood flow thereby permitting longer equilibration times at both sites. Heart rate decreases at the time (deFur et al. 1985). Hemocyanin levels begin a sharp decline (Figure 2).

During exuviation blood PO_2 falls to very low levels, both at the gills and the tissues (Figure 2). Blood PCO_2 rises and pH falls from its premolt levels (Figure 2). However, because of premolt alkalosis, blood pH never drops below the intermolt value, at least not as long as the animal survives. This is true even though PCO_2 is high and lactate begins to accumulate (Figure 2), which is very unusual and certainly a critical event in the success of a molt. This conclusion is underscored by what happens in animals that do not survive a molt. We made a number of measurements on animals that either did not shed or emerged with morphological aberrations of the gills and legs and died within several hours. In those animals lactate was very high; blood PO_2 and pH were lower than the intermolt values, and pH fell on at least one occasion well below 7.0 (Table 1). These data clearly indicate that the immediate cause of death was in fact the failure of the respiratory system.

But what is responsible for an unsuccessful molt? It seems obvious that, if the osmoregulatory (see below) and cardiovascular systems are responsible for the pressure that permits exuviation, the failure to exuviate normally may be due to osmoregulatory or cardiovascular disease. This suggestion is strongly supported by observations on two animals that failed to emerge and died. In those two, blood pressure never rose to the levels shown in Figure 3, indicating that their osmoregulatory and cardiovascular systems were simply unable to generate the very high pressures required for exuviation.

In early postmolt the crab is weak. pH and Hc levels are at their lowest; lactate levels are at their highest (Figure 2). This is probably due to the lag between production and reoxidation of lactate rather than a high level of anaerobic metabolism during the postmolt. It is not true that the scaphognathite cannot work when it is soft, but it is true that it does not work as well. Ventilation is only one-half of the intermolt rate (Figure 2), but blood PO_2 rises to levels much higher than intermolt values while ventilation is still low (Figure 2). This finding gives us a clue to the answer to our original question. At the same time that the animal has reverted to a more primitive form of skeletal support, it has also reverted to a more primitive form of gas exchange, namely cutaneous.

The intermolt carapace is effectively gas tight; however, the new cuticle is no less permeable to oxygen than any other tissue (Mangum et al. 1985). The epidermis, where the new cuticle is being formed, is well within the limiting diffusion distance for O_2 from the ambient medium. More importantly, so are the superficial blood spaces. The blood-medium diffusion distance across the general body surface of an early postmolt crab is less than twice as great as the distance across the gill of an intermolt crab. The whole animal becomes a gill, so to speak.

Blood pressure begins to decline even though water uptake is continuing (Figure 3), which may seem to be paradoxical. However, this is not really surprising and it is almost certainly due to increased urine output. The basic mechanism of urine formation in crabs is filtration. Blood hydrostatic pressure, which forces water out through leaky epithelia such as renal membranes, is kept higher than colloid osmotic pressure. Colloid osmotic pressure, arising from the hydrophilic nature of plasma proteins such as Hcs, tends to suck water back in (Figure 4). In intermolt animals the excess of hydrostatic over colloid osmotic pressure is very small, which is why Hc levels have to be so low. However, in postmolt animals with their hydrostatic skeletons and only one-fifth of their normal complement of Hc, that margin increases by an order of magnitude. The net result must be increased urine flow.

Later in postmolt, when hardening is initiated and gas permeability begins to return to intermolt levels, the animal begins to hyperventilate which continues throughout the postmolt (Figure 3). Blood lactate, pH, and PCO_2 slowly return to normal so these factors should no longer perturb

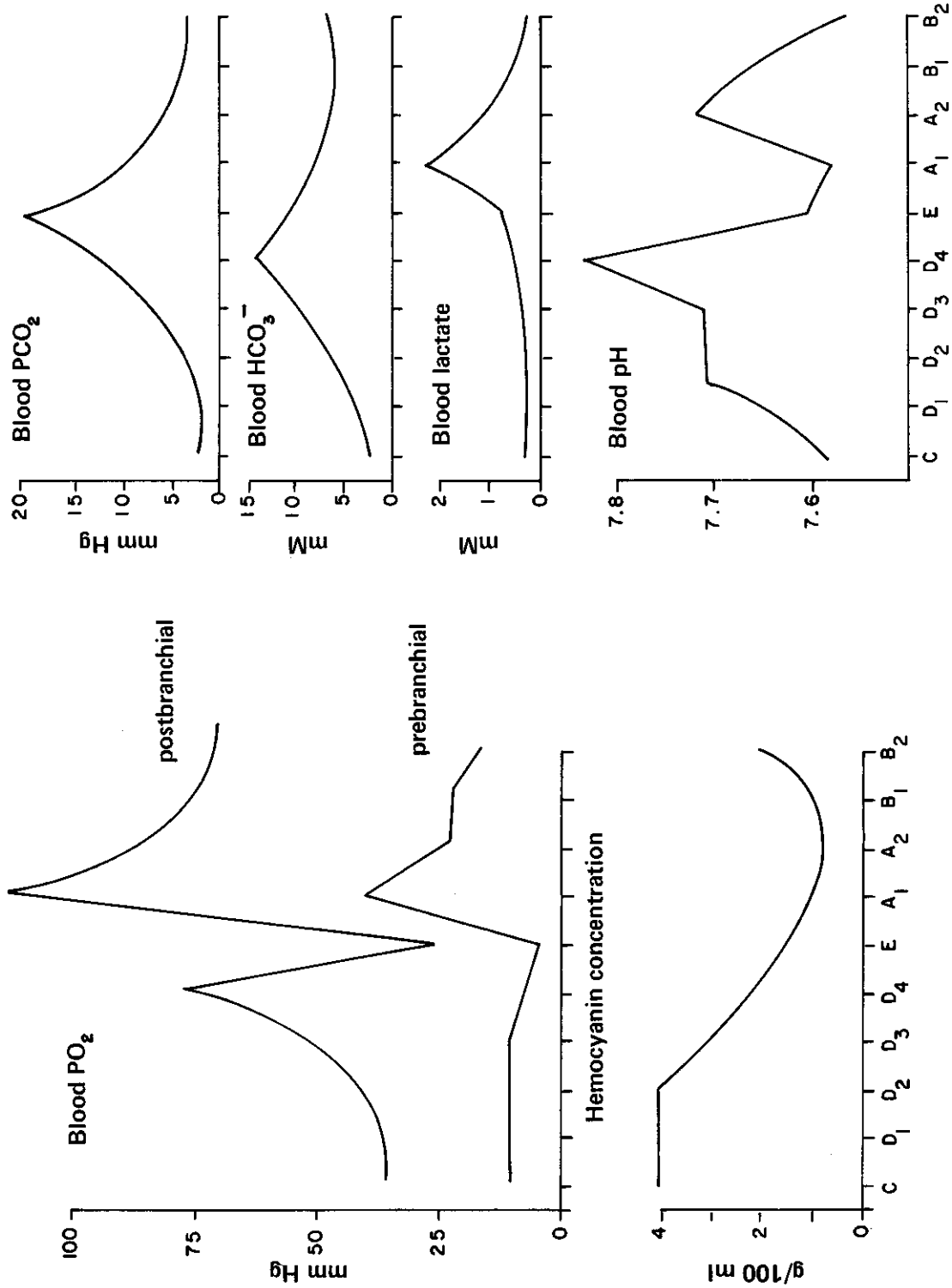

Figure 2. Changes in blood respiratory and metabolic variables during intermolt cycle (21 to 26°C, 31 to 35 ppt, ambient PO_2 145 to 159 mm Hg). (Data from Mangum et al. 1985.)

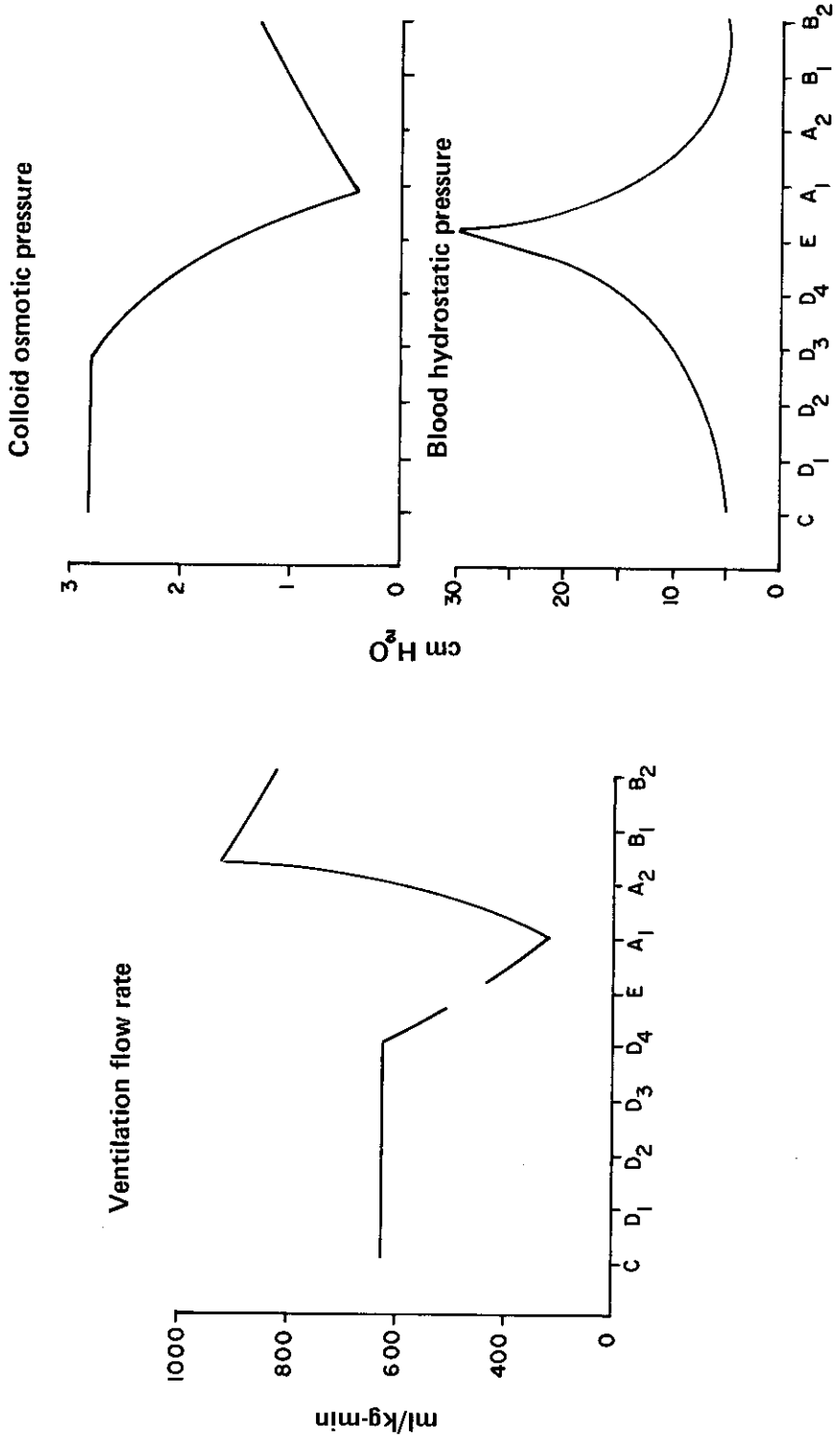

Figure 3. Changes in ventilatory and cardiovascular variables during intermolt cycle (21 to 26°C, 31 to 32 ppt, ambient PO_2 145 to 159 mm Hg). (Data from deFur et al. 1985.)

TABLE 1.

Examples of blood respiratory and metabolic variables in animals that did not survive a molt (21 to 26°C, 31 to 35 ppt, ambient PO_2 145 to 159 mm Hg).

pH	6.30 – 7.12
PCO_2 (mm Hg)	19.0
PO_2 (mm Hg)	0.5
Lactate (mM)	3.40

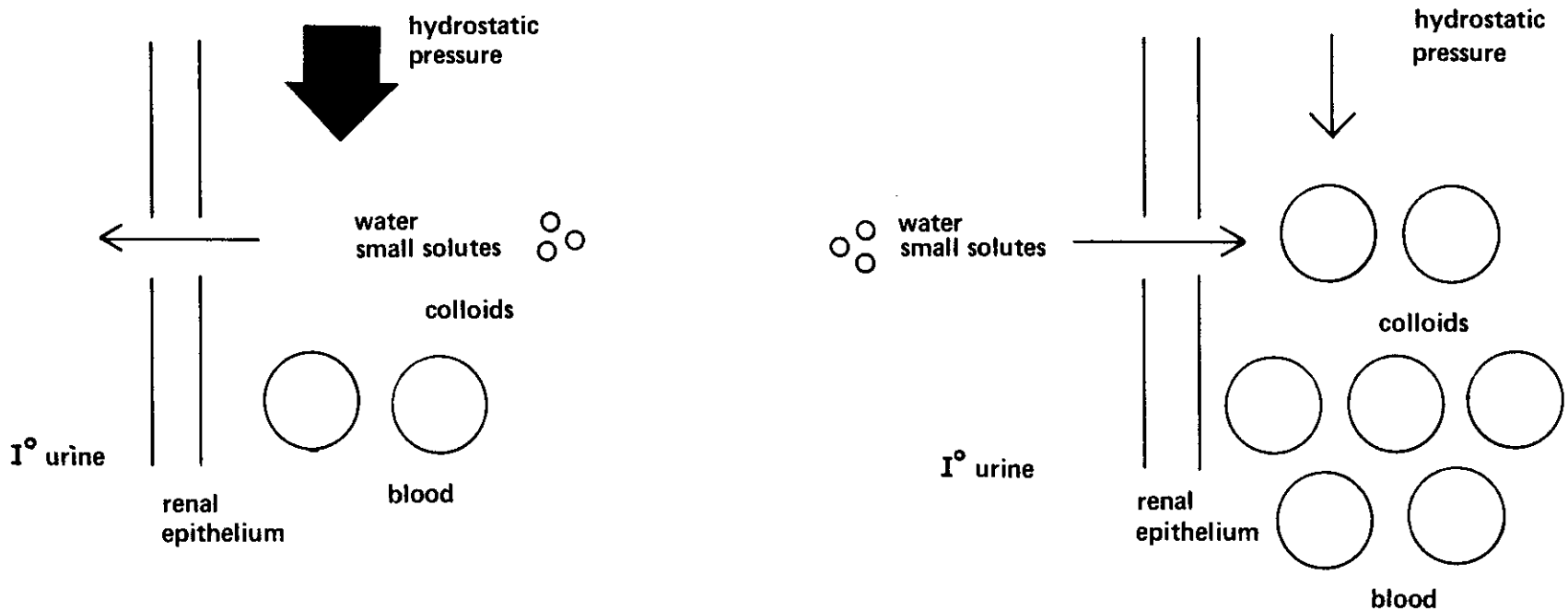

Figure 4. Relationship between blood hydrostatic pressure and colloid osmotic pressure. Width of arrows at top represents relative magnitudes of hydrostatic pressure. Number of circles represents the number of osmotically active colloids.

the O_2 transport system. However, Hc levels continue to remain low, which is somewhat surprising. In fact there should be no selection pressure for maintaining high Hc levels because blood PO_2 remains elevated, probably as a result of hyperventilation; the Hc molecule should not work under those conditions. The O_2 affinity of blue crab Hc under ionic conditions in an early postmolt animal is a little less than 10 mm Hg; however, tissue blood PO_2 is so high that the molecule would not unload–it would remain from 83 to 99% oxygenated (Figure 5).

Can the crab solve this problem? At the outset I said that blue crab Hc is allosterically modulated. However, the system is designed to be modulated during hypoxia by means of lactate production and Ca^{+2} dissolution (Truchot 1980, Mangum 1985). Here we are talking about "hyperoxia" for which the system is not designed. There is, however, another mechanism of adaptation that may operate during adaptation to low salinity, namely, a fundamental change in the Hc molecule (Mason et al. 1983). Hemocyanins are built of more subunits than needed for assembly of the molecule. If the respiratory properties of the subunits differ from one another, then the crab could modify the overall properties of the system by putting the molecule together with different proportions of the subunits. The ideal setting for such an adaptation would be a time of rapid change in net synthesis or degradation, as during molting. Despite the large changes in Hc levels during the molt cycle, however, there is no change in the subunit composition of the Hc molecule and none in the intrinsic properties of the molecule (Mangum et al. 1985).

Intermediary Metabolism

In the past 15 years or so it has been shown that many animals utilize pathways of anaerobic metabolism which are more efficient that the mammalian version of glycolysis in terms of energy production. This capability is often correlated with a high tolerance of hypoxia. We had no reason to suppose that intermolt crabs possess this capability but we had to be sure that the success of the molt was not due to the transient acquisition of it, and it was not. Not only did the activities of glycolytic enzyme systems remain unchanged but there was no sign of alternative end products

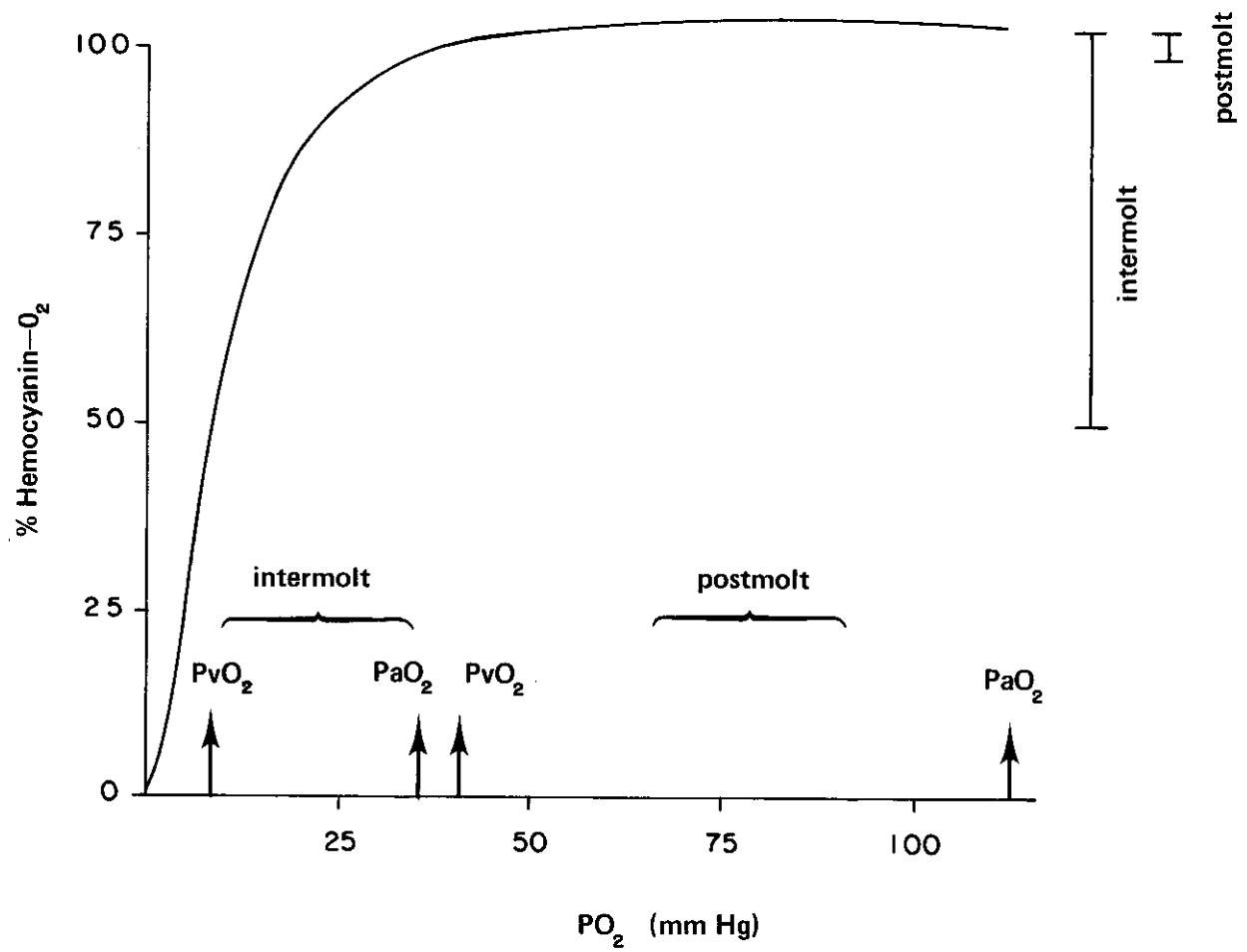

Figure 5. Relationship between O_2 binding of Hc and blood PO_2 in intermolt and postmolt crabs. Left member of each pair of arrows directed from abscissa designates value at tissues; right member designates value at gill. Vertical lines at far right indicate amount of HcO_2 delivered to tissues (data from Mangum et al. 1985).

(Fields 1985). The crab is locked into classical glycolysis. However, there are two metabolic changes of interest. In the epidermis (but not in other tissues), hexokinase activity rises during premolt. This enzyme catalyzes the first step in the metabolism of free glucose, which could facilitate glycolysis. Secondly, during premolt the activities of pyruvate kinase and lactate dehydrogenase decrease in locomotor muscle (but not in other tissues). These enzymes are central to anaerobic pathways and the decreases are very likely responsible for the cessation of high levels of motor activity, which require input from anaerobic pathways.

Water Uptake

It is generally believed that water uptake during a molt occurs through the intestinal epithelium, a phenomenon that has been demonstrated directly in osmoconforming species such as the lobster (Mykles 1980), which lacks the ionic machinery necessary to actively absorb Na^+ at the gill. Dr. W. A. Van Engel (pers. comm.) has shown that the blue crab inflates its gut with seawater during a molt, which almost certainly contributes to the rise in blood pressure. However, this process is probably better termed "imbibition" rather than "drinking," which implies transepithelial water movement. In the blue crab, a fairly strong osmoregulator, water uptake during a molt occurs primarily at the gill (Cantelmo 1976). The mechanism may be isosmotic fluid transport by the same enzymes that function during active salt uptake at low salinity. Even in isosmotic animals held at high salinity, clear increases in the activity of the branchial $Na^+ + K^+ -$ ATPase coincide with the onset of water uptake and persist throughout postmolt (Figure 6). These enzymes transport Na^+. For many years investigators have been searching for comparable enzymes that transport Cl^-. A popular hypothesis has been an enzyme that can carry out a $Cl^- - HCO_3^-$ exchange. However, no one has been able to find an enzyme with the properties that ideally it should have, namely, activation by both members of the postulated exchange. There is an enzyme that is activated by HCO_3^- and has a small and absolute requirement for Cl^-. During premolt the activity of this enzyme appears to increase in the gills of the blue crab, but the trend is not shown in Figure 6 because it was significant at only one stage and it preceded by far the onset of water uptake.

Calcification

During a molt the activity of $Na^+ + K^+ -$ ATPase increases in the epidermis (but not the gut) as well as in the gill, and the timing concides with that of Ca deposition (Figure 6). Earlier workers reported that calcification was sensitive to ouabain, a specific inhibitor of this enzyme. The mechanism of action, however, remains obscure and the chronology is also consistent with the possibility that the increase is associated with water uptake across the cuticle and not calcification.

It is unlikely that the soft-crab industry could use ouabain to keep crabs soft. While a crab can live for a week in water containing 10^{-3} M ouabain, reflecting its impermeability, injection of the inhibitor into the blood causes immediate neurological damage resulting in impairment of ventilatory and cardiovascular functions followed by death (Mangum, deFur and Polites, unpublished observations). Incidentally, it also appears to be unlikely that crabs can be kept soft by injecting inhibitors of protein tanning. Twice daily injections of mimosine and kajic acid (final concentration 5×10^{-4} M), beginning at A_1 and continuing for two days had no perceptible effect on hardening, although the effect of gentisic acid was less clear. In all three cases mortality was heavy (Mangum, unpublished observations).

The mechanism of action of another enzyme, carbonic anhydrase (CA), is ostensibly more clear. This enzyme catalyzes the equilibrium reactions between molecular CO_2 and water and carbonic acid, which are believed to furnish the form of CO_2 that will be precipitated:

$$\xrightarrow{CA}$$
$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

So it remains a puzzle that CA activity in the epidermis does not increase until postmolt, long after Ca deposition is initiated (Figure 6). The increase may, however, be responsible for the transition from low levels of calcification to maximal rates.

In osmoregulating crabs and also other animals the gills are specialized for different functions. The anterior gills, which have very thin epithelia, are the gas exchangers. The posterior gills, which have more tissue, are the salt pumps. The CA activity in both sets increases dramatically during the molt cycle, but at quite different stages. The gills, of course, are not calcified so increases in activity cannot be associated with that process. When an ion is taken up from the medium, electrochemical balance across the transporting epithelium must be maintained often by the extrusion of another ion of the same charge. Henry and Cameron (1983) have raised the possibility that during hyperosmotic regulation the branchial CA supplies the counterions for Na^+ and Cl^- uptake in the form of H^+ and HCO_3^-. However, in isosmotic animals taking up water prior to a molt, the synchronization between the two enzymes is not very tight, and we are still left with the problem of finding a carrier for the postulated exchange of Cl^- for HCO_3^-.

Additionally, there is an aspect of molting that presents a special problem for the hypothesis that CA functions to provide the counterions exchanged for the NaCl absorbed during isosmotic water uptake. For many years it has been known that most of the Ca laid down in the new skeleton must be taken up from the medium [see Sparkes and Greenaway (1985) for an interesting exception]. It is becoming increasingly clear that the HCO_3^- must also be taken up from the ambient medium (Dejours and

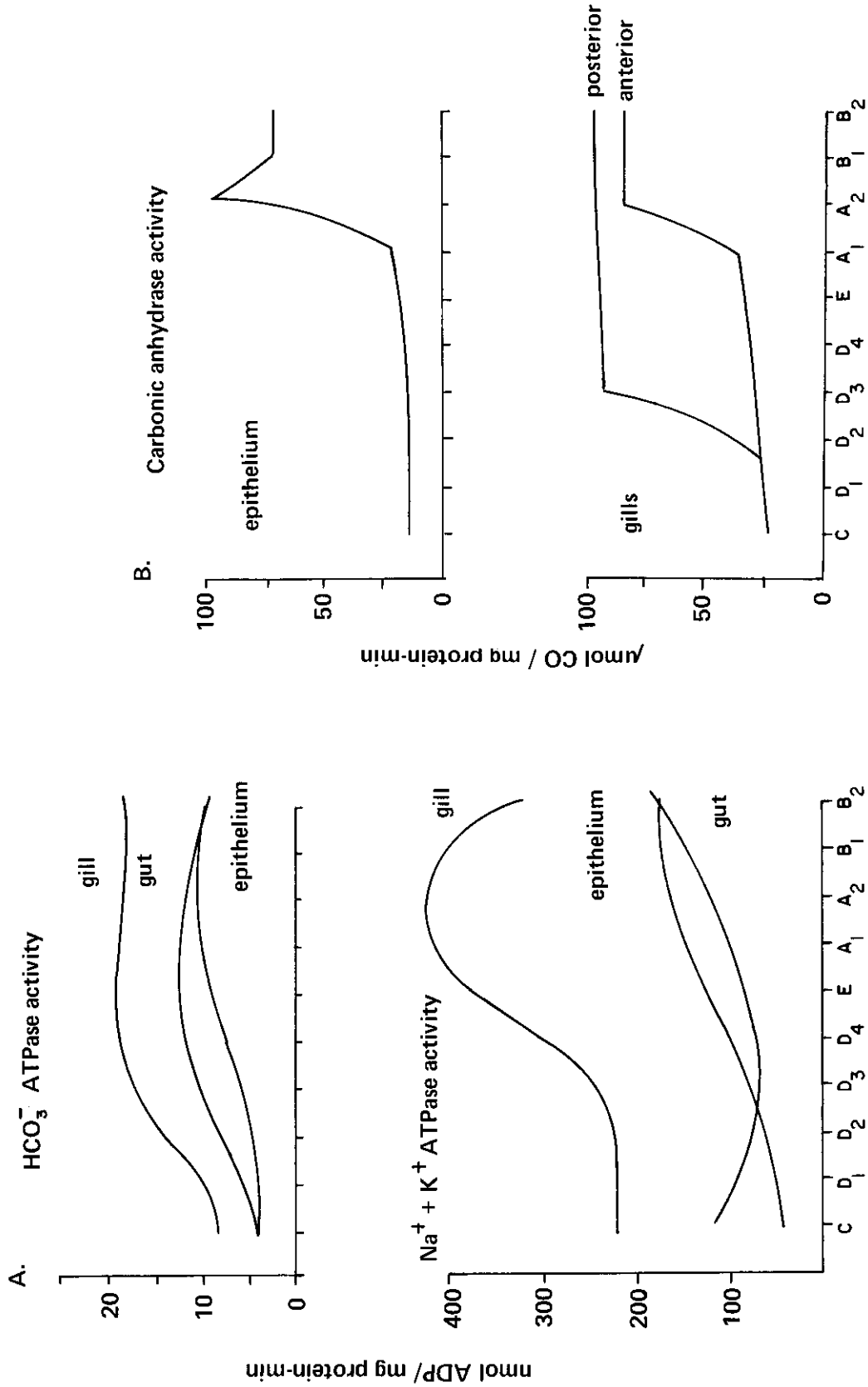

Figure 6. (A) Activities of $Na^+ + K^+$ – ATPase and HCO_3^- – ATPase in the posterior gills, gut and epidermis of the blue crab during intermolt cycle (data from Towle and Mangum 1985). (B) Activities of carbonic anhydrase in the anterior and posterior gills and in the epidermis (data from Henry and Kormanik 1985).

Beekenkamp 1978, Cameron [pers. comm.]), and for the same reasons. Despite those increases in blood HCO_3^-, there is not nearly enough inside the animal. So if HCO_3^- were extruded for the Cl^- taken up isosmotically, the gill would immediately have to turn around and take up the HCO_3^- again for calcification! That is probably not possible as I have stated it because the gill is ventilated at such a rate that the extruded HCO_3^- would be lost. It is conceivable that the extrusion-resorption takes place within the gill epithelium (Figure 7) although how the process could work at the molecular level is far from clear. We know that the $Na^+ + K^+$ – ATPases are located on the blood side of the gill epithelium and it is possible that the postulated anion pumps are as well. However, the very kinetics of the process would suggest that the same carrier cannot perform in both directions at once. All of these problems remain for future investigation.

Changes in Intracellular Free Amino Acids

Changes in the intracellular pool of free amino acids (FAA) are usually associated with volume readjustment during adaptation to a change in salinity. However, two previous investigations showed that the size of the pool changes during the molt cycle. In one study the change was attributed to a cycle of muscle fiber atrophy and reformation that occurs in the claw (Yamoaka and Skinner 1976; also Skinner, pers. comm.). Muscle proteins must be broken down to lower the volume of the claw to the point where the crab can get it out, and then the muscle proteins must be resynthesized so that the crab can use the claw again. These events are reflected in the changes of O_2 uptake seen in isolated claw muscle tissue (Figure 1). The claw, incidentally, is not functional at this time, which is not disadvantageous because the crab is not feeding and because a soft claw would not be of much use for defense. In another study a decrease in FAA was found in muscles that almost certainly do not atrophy (Dûchateau et al. 1959), judging from their uninterrupted functional capabilities. This finding could conceivably be just a special form of volume readjustment following a salinity change. A hyperosmotic crab was taking up hypoosmotic water, which would swell the tissues. But in blue crabs taking up isosmotic water there are still decreases in the FAA pool in somatic muscles (Figure 8). The FAA could either be used in biosyntheses or simply excreted. In either case the reduction of the size of the FAA pool should lower tissue water content, which

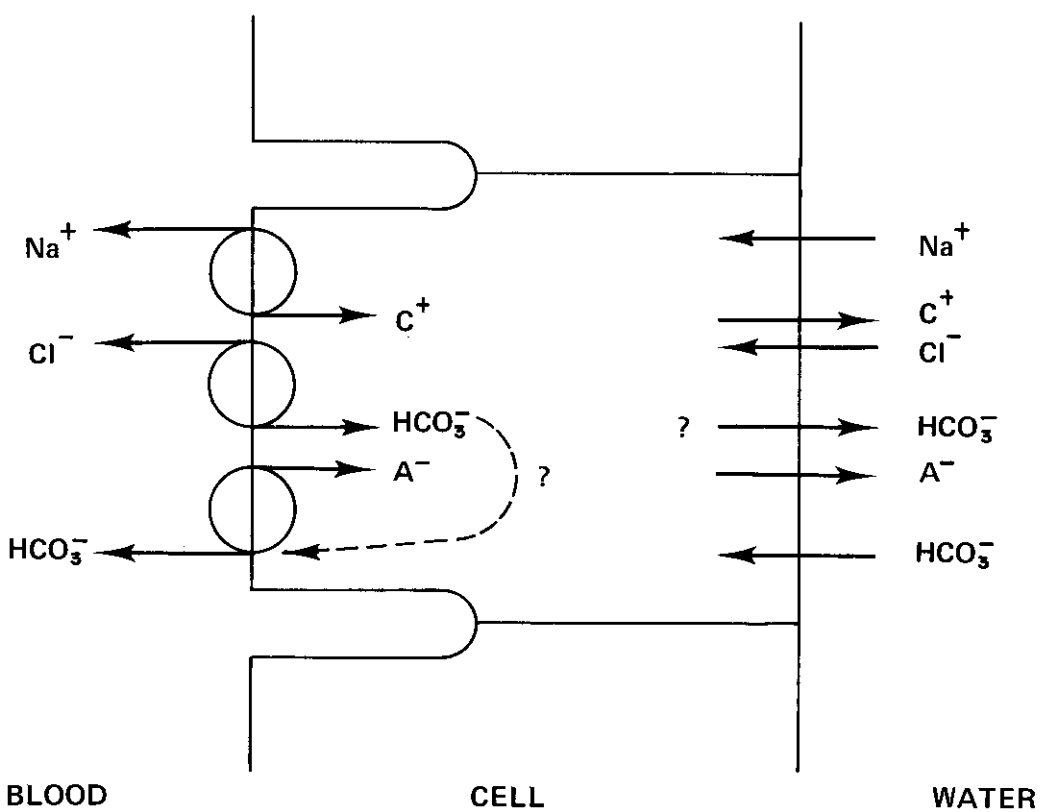

Figure 7. Model of gill cell showing complexity of the postulated movements of inorganic ions during a molt. Ions move passively into the branchial epithelium from the seawater. Na^+ is absorbed in exchange for an unspecified monovalent cation and Cl^- perhaps for HCO_3^-. HCO_3^- is also absorbed in exchange for an unspecified monovalent anion. The same exchanges take place from the gill cell to the blood by active transport. At least some of the HCO_3^- moved here is recycled.

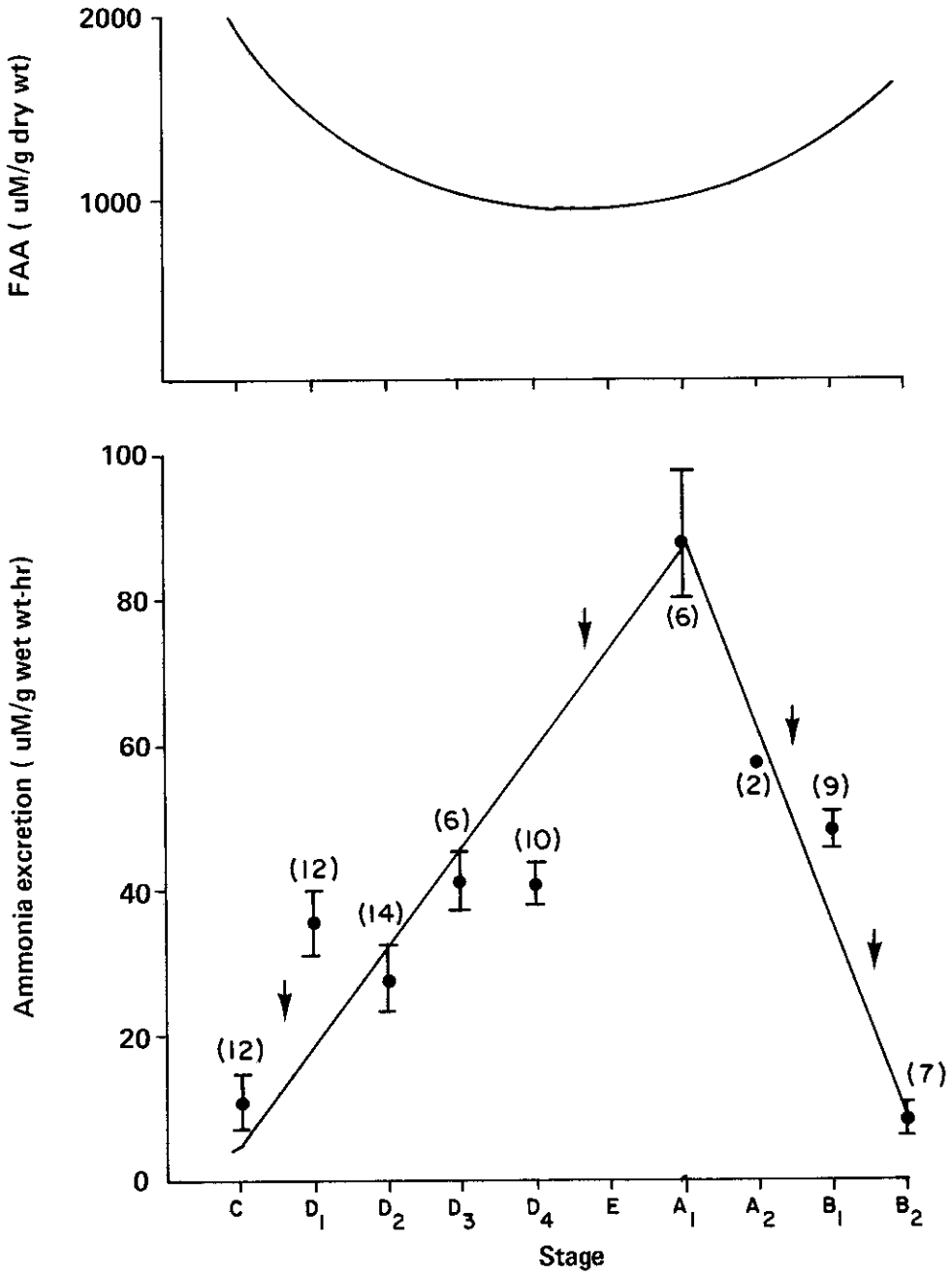

Figure 8. Changes in free amino acids (FAA) in somatic muscle (data from Wheatly 1985) and ammonia excretion (Mangum, unpublished data) during intermolt cycle. For ammonia excretion, mean ± S.E. (N). Postmolt values adjusted for change in body weight due to water uptake. Arrows indicate significant ($P < 0.01$ according to Student's t test) changes, analyzed as paired observations on the same individuals (N = 2 to 9).

has in fact been observed (Wheatly 1985), and by implication the volume of the tissues. Assuming moderate values for blood flow and clearance, the increase in ammonia excretion (Figure 8) is more than enough to explain the fate of the amino group of the FAA, although the fate of the carbon skeleton remains unknown. Thus our data suggest that the loss of FAA from muscle serves to shrink the organs and to faciliate exuviation. Whether it also furnishes a keto acid for the metabolic processes associated with formation of the new skeleton cannot yet be decided.

The finding of isosmotic loss of FAA from tissues that were never swollen has interesting implications for the postulated mechanisms of extrusion. According to the hypothesis formulated by Pierce and Greenberg (1973), the gates in the cell membrane that normally prevent FAA loss pop open passively due to stretching in swollen cells, although an active process is required to close them again after volume readjustment. This simple model, which was formulated in the context of bivalve mollusc cells, does not provide for a passively generated force in unswollen cells, suggesting that an alternative process may occur in crustacean muscle, at least during a molt and possibly during adaptation to low salinity as well.

SUMMARY

A molt is possible essentially for four reasons: (1) an alkalosis in the premolt anticipates an acidosis that would otherwise arise during exuviation when the gas exchanger does not work very well, (2) the crab is able to revert to more primitive forms of skeletal support and gas exchange, (3) the cardiovascular and osmoregulatory systems are able to generate sufficient hydrostatic pressure to split open the old skeleton, and (4) at least the muscle tissues are able to reduce their volume by extruding organic osmolytes from unswollen cells. These mechanisms are very fragile, however, and they often fail. When that happens there are no special metabolic mechanisms to sustain life.

Changes in carbonic anhydrase activity in the gill and epidermis are clear, but their significance is not. It is very possible that this enzyme is not playing the role assigned to it in intermolt animals.

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REFERENCES CITED

Cantelmo, A. 1976. Water permeability of isolated tissues from three species of decapod crustaceans with respect to osmotic conditions and the effects of neuroendocrine control. New York, N.Y.: City College, City Univ. of New York. 88 p. Dissertation.

Carpenter, J. H. and D. G. Cargo. 1957. Oxygen requirement and mortality of the blue crab in the Chesapeake Bay. *Chesapeake Bay Inst. Tech. Rep.* 13:22 p.

deFur, P. L., C. P. Mangum and B. R. McMahon. 1985. Cardiovascular and ventilatory changes during ecdysis in the blue crab, *Callinectes sapidus* Rathbun. *J. Crust. Biol.* 5:207–215.

Dejours, P. and H. Beekenkamp. 1978. L'Equilibre acide-base de l'hémolymph au cours de la mue chèz l'Ecrivisse. *C. R. Acad. Sci. Paris* 286D:1895–1898.

Dûchateau, G., M. Florkin and C. Jeuniaux. 1959. Composante amine acide des tissus chèz les Crustaces. I. Composantes amine acide des muscles de *Carcinus maenas* L. lors du passage de l'eau de mer à l'eau saumâtre et au cours de la mue. *Arch. Int. Physiol. Biochem.* 67:489–500.

Fields, J. H. A. 1985. A note on anaerobic metabolism in *Callinectes sapidus* during the intermoult cycle. *J. Crust. Biol.* 5:242–248.

Henry, R. P. and J. N. Cameron. 1983. The role of branchial carbonic anhydrase in respiration, ion regulation and acid-base balance in the aquatic *Callinectes sapidus* and the terrestrial *Gecarcinus lateralis*. *J. Exp. Biol.* 103:205–223.

Henry, R. P. and G. A. Kormanik. 1985. Carbonic anhydrase activity and calcium deposition during the molt cycle of the blue crab, *Callinectes sapidus*. *J. Crust. Biol.* 5:234–241.

Lewis, E. G. and P. A. Haefner. 1976. Oxygen consumption of the blue crab, *Callinectes sapidus* Rathbun, from proecdysis to postecdysis. *Comp. Biochem. Physiol.* 54:55–60.

Mangum, C. P. 1985. Oxygen transport in invertebrates. *Am. J. Physiol.* 248:R505–R514.

_____, B. R. McMahon, P. L. deFur and M. G. Wheatly. 1985. Gas exchange, acid-base balance and the oxygen supply to tissue during a molt of the blue crab *Callinectes sapidus*. *J. Crust. Biol.* 5:188–206.

Mangum, C. P. and A. L. Weiland. 1975. The function of hemocyanin in respiration of the blue crab *Callinectes sapidus*. *J. Exp. Zool.* 193:257–264.

Mason, R. P., C. P. Mangum and G. Godette. 1983. The influence of inorganic ions and acclimation salinity on hemocyanin-oxygen binding in the blue crab *Callinectes sapidus*. *Biol. Bull. (Woods Hole)* 164:104–123.

Mauro, N. A. and C. P. Mangum. 1982. The role of the blood in the temperature dependence of oxidative metabolism in decapod crustaceans. I. Intraspecific responses to seasonal differences in temperature. *J. Exp. Zool.* 219:179–188.

McMahon, B. R. 1981. Oxygen uptake and acid-base balance during activity in decapod crustaceans. Herreid, C. F. and Fourtner, C. A. eds. *Locomotion and Energetics in Arthropods.* New York: Plenum Press; 299–336.

Mykles, D. M. 1980. The mechanism of fluid absorption in the American lobster, *Homarus americanus*. *J. Exp. Biol.* 84:89–101.

Passano, L. M. 1960. Molting and its control. Waterman, T. H. ed. *The Physiology of Crustacea.* New York: Academic Press; Vol. 1, 473–536.

Pierce, S. K. and M. J. Greenberg. 1973. The initiation and control of free amino acid regulation of cell volume in salinity-stressed marine bivalves. *J. Exp. Biol.* 59:435–446.

Sparkes, S. and P. Greenaway. 1985. The hemolymph as a storage site for cuticular ions during premoult in the freshwater land crab *Holthuisana transversa*. *J. Exp. Biol.* 113:43–54.

Towle, D. W. and C. P. Mangum. 1985. Ionic regulation and transport ATPase activities during the molt cycle in the blue crab, *Callinectes sapidus*. *J. Crust. Biol.* 5:216–222.

Truchot, J. P. 1980. Lactate increases the oxygen affinity of crab hemocyanin. *J. Exp. Zool.* 294:205–208.

Wheatly, M. G. 1985. Free amino acid and inorganic ion regulation in the whole muscle and hemolymph of the blue crab *Callinectes sapidus* Rathbun in relation to the molting cycle. *J. Crust. Biol.* 5:223–233.

Yamoaka, L. H. and D. M. Skinner. 1976. Free amino acid pools in muscle and hemolymph during the molt cycle of the land crab, *Gecarcinus lateralis*. *Comp. Biochem. Physiol.* 55:129–134.

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BLUE CRAB (*CALLINECTES SAPIDUS* RATHBUN) VIRUSES AND THE DISEASES THEY CAUSE

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INTRODUCTION

The first virus of a marine invertebrate was found about 20 years ago (Vago 1966). Since then, more than 40 viruses have been reported from a variety of marine invertebrates and many of them are from crustaceans, mainly decapods (Johnson 1983, 1984; Lightner and Redman 1985). The viruses of decapods can seldom be assigned with certainty to particular families because their biochemical and immunological characteristics are incompletely known. In development and morphology, the viruses are related to the various families listed in Table 1. Almost all of the decapod viruses discovered so far are from species of portunid crabs and penaeid shrimp, presumably reflecting the fact that these decapod groups have been most intensely studied. Viruses are important pathogens of cultured penaeid shrimp (Lightner 1983) and some species cause mortality in wild and captive populations of crabs (Johnson 1983, 1984). Seven, perhaps eight, viruses occur in the blue crab *Callinectes sapidus* Rathbun and some of them are associated with disease in their hosts.

DNA VIRUSES OF THE BLUE CRAB

Herpes-like Virus

Herpes-like virus (HLV) was found in crabs from Assawoman Bay, Delaware, and Chincoteague Bay, Virginia (Johnson 1976a, 1978). It has not been found elsewhere.

HLV infects hemocytes, occasionally hemopoietic cells, and probably connective-tissue cells and epithelial cells of the gill. Infected nuclei are greatly hypertrophied and either contain Feulgen-positive granules or are homogeneous and faintly to deeply Feulgen positive. Infected nuclei may contain large Feulgen-negative inclusions and similar inclusions regularly occur in the cytoplasm (Figure 1). The cytoplasm of severely infected cells is reduced to a thin rim, and release of virus is by lysis of the nucleus. Hemolymph of a terminally infected crab is filled with free virus and granular material probably derived from the breaking up of the cytoplasmic and nuclear inclusions. The central cylindrical nucleoid of HLV is surrounded by a toroid and the envelope of a fully developed virion consists of two membranes. The enveloped virion is hexagonal with a diameter of 185 to 214 nm (Figure 2). Entire development, including envelopment, takes place in the nucleus.

Prevalence of HLV in a natural population of juvenile blue crabs can be 13% (Johnson 1983). Infected crabs appear normal until shortly before death, when they become inactive and cease feeding. Hemolymph withdrawn from terminally infected crabs is an opaque, chalky white, and has lost the capacity to gel. Final diagnosis of HLV disease depends on finding typical infected cells in paraffin-embedded tissue sections, but reasonably firm diagnosis of terminal infections can be made on the basis of the hemolymph being chalky white and nongelling.

Death probably occurs because of hemocyte dysfunction and loss. Whether HLV-infected crabs ever recover is unknown. Crabs injected with hemolymph from moribund HLV-infected crabs can die in 30 to 40 days (Johnson 1978), but natural infections and some experimental ones may take much longer before causing death. Moderate to heavy HLV infections were found in juvenile crabs that had been kept in the laboratory for 50 days in separate containers with separate water supplies, showing that virus was present before capture, and some experimentally infected crabs were only lightly infected and still normal in appearance 65 days after injection (Johnson 1984). HLV caused an epizootic with a high mortality rate in juvenile crabs held in separate containers but with a common water supply, indicating that HLV disease is highly infectious by the water route.

Baculoviruses

Both of the blue crab baculoviruses are "nonoccluded." That is, the virions lie free in the nucleus rather than being "occluded" within proteinaceous occlusion bodies that are often polyhedral. Nuclei infected with baculoviruses are hypertrophied, usually evenly Feulgen positive and often rimmed with strongly staining chromatin.

Baculovirus A (Baculo-A) infection is widespread along the Atlantic coast and its distribution in blue crabs may be general. Prevalence of the virus in blue crab populations usually varies from 4 to 20%, although 18 of 34 crabs (52%) were infected in one group taken from Chincoteague Bay, VA (Johnson 1976b, 1983). Baculo-A infects nuclei in the epithelium of the hepatopancreas. Infected nuclei are typically twice normal size and stain rather weakly by the Feulgen method (Figure 3). Even in heavy infections,

the virus appears not to affect the crabs, probably because it is almost always focal in nature and epithelial cells of the hepatopancreas are constantly being replaced by stem cells, which are not themselves infected. Development of Baculo-A is associated with intranuclear tubule-like structures which probably represent forming capsids (Figure 4). The enveloped virion is about 70 × 285 nm, and virions tend to form ordered arrays.

Infection with Baculo-A can be diagnosed with the light microscope by presence of hypertrophied nuclei in the epithelium of the hepatopancreas.

Baculovirus B (Baculo-B) of hemocytes occurs in crabs from Chesapeake Bay and its tributaries. Nuclei of hemopoietic cells and hemocytes are infected by Baculo-B. Infected nuclei may be completely homogeneous or rimmed with chromatin (Figure 5). Occasionally, there are hyperchromatic areas in the center of the nucleus. Nuclear hypertrophy is not as marked as in HLV (compare Figures 1 and 5), and there are no refractile nuclear or cytoplasmic inclusions. Usually, Baculo-B-infected nuclei are more strongly Feulgen positive than ones infected with either HLV or Baculo-A. Virions have tapered and rounded ends, so that the virion is slightly ovoid (Figure 6). Enveloped virions are approximately 100 × 335 nm. They have a tendency to form ordered arrays in the nucleoplasm, and their development is associated with intranuclear vesicles rather than long tubule-like structures as in Baculo-A. Diagnosis depends on finding characteristic hypertrophied nuclei in hemocytes by light microscopy.

The effect of Baculo-B on its host is unknown. Some of the crabs studied had naturally acquired infections, but others had been used in attempts to transmit various viruses (Johnson 1983). The latter may have had preexisting infections or the virus might have been accidentally transmitted to them. Some of the experimental crabs were sick, but because they were also infected with other viruses, the effect of Baculo-B could not be determined. Heavy infections result in loss and dysfunction of many hemocytes. One may suspect that the host is affected adversely in such cases.

RNA VIRUSES OF THE BLUE CRAB

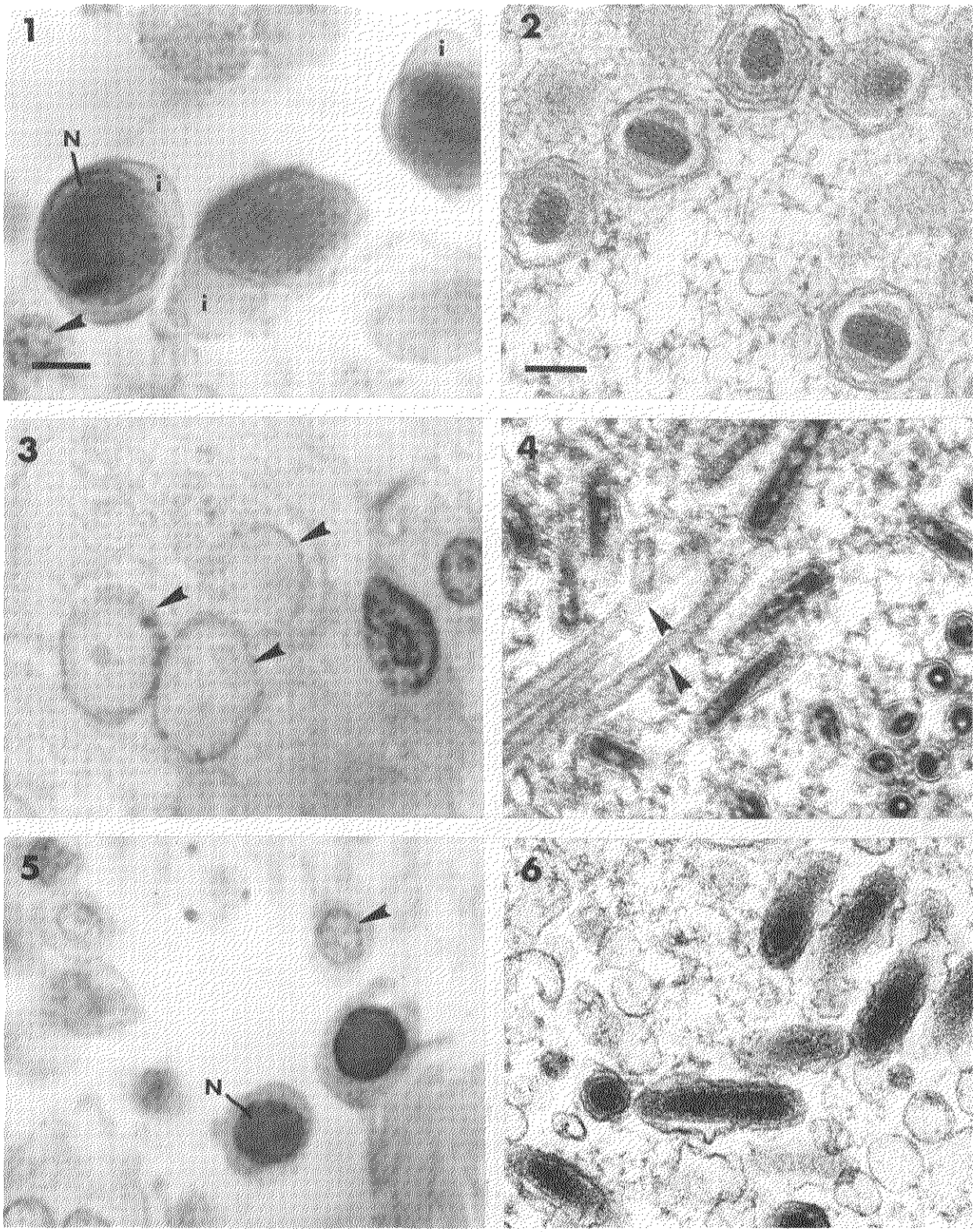
Reo-like Virus

Reo-like virus (RLV) is common in crabs from Chincoteague and Chesapeake bays, and is associated with fatal disease (Johnson and Bodammer 1975; Johnson 1983, 1984). Ectodermally and mesodermally derived tissues are infected, principally hemocytes, hemopoietic tissue and the glia of the nervous system. Epidermis, gill and bladder epithelia, endothelia of blood vessels, Y-organ, and various connective-tissue cells may also be infected. Infected hemocytes and hemopoietic tissue contain basophilic, Feulgen-negative, cytoplasmic inclusions that often are angulate but

TABLE 1.

Viral families with known or presumed members in decapods. (ds = double stranded; ss = single stranded)

Family	Host (Number of Viral Species)	Reference
Herpesviridae ds DNA, enveloped, nucleus	*Callinectes sapidus* (1) *Rhithropanopeus harrisii* (1)	Johnson 1976a Payen and Bonami 1979
Baculoviridae ds DNA, enveloped, nucleus	*Callinectes sapidus* (2) *Carcinus maenas* (1) *Carcinus mediterraneus* (1) *Penaeus* spp. (3)	Johnson 1976b, 1983 Bazin et al. 1974 Pappalardo and Bonami 1979 Couch 1974, Sano et al. 1981, Lightner and Redman 1981
Parvoviridae ss DNA, nonenveloped, nucleus	*Penaeus* spp. (1)	Lightner and Redman 1985
Reoviridae ds RNA (10–12 segments), nonenveloped, cytoplasm	*Callinectes sapidus* (1) *Carcinus mediterraneus* (1) *Macropipus depurator* (1)	Johnson and Bodammer 1975 Bonami 1976 Vago 1966
Bunyaviridae ss RNA, enveloped, cytoplasm	*Carcinus maenas* (1) *Carcinus mediterraneus* and *Macropipus depurator* (2)	Bang 1971 Bonami and Vago 1971, Zerbib et al. 1975
Rhabdoviridae ss RNA, enveloped, cytoplasm	*Callinectes sapidus* (2 or 3) *Carcinus maenas* (1)	Jahromi 1977, Yudin and Clark 1978, Johnson and Farley 1980 Chassard-Bouchaud and Hubert 1975
Picornaviridae ss RNA, nonenveloped, cytoplasm	*Callinectes sapidus* (1) *Hemigrapsus oregonensis* (1) *Macropipus depurator* (2) *Penaeus* spp. (1)	Johnson 1978 Kuris et al. 1979 Bonami 1976 Lightner et al. 1983



Figures 1 through 6. (1) Hemocytes infected with HLV. Arrow points to a normal nucleus. Bar = 10 μm. N, infected nucleus; i, cytoplasmic inclusion. Figures 3 and 5 are to the same scale. (2) Electron micrograph of HLV. Bar = 106 nm. Figures 4 and 6 are to the same scale. (3) Baculo-A infecting nuclei of the hepatopancreatic epithelium (arrows). (4) Electron micrograph of Baculo-A. Note tubule-like structures (arrows). (5) Hemocytes infected with Baculo-B. Arrow indicates a normal nucleus. N, infected nucleus. (6) Electron micrograph of Baculo-B. Note associated vesicles.

may be rounded. Major portions of the glia of the brain or thoracic ganglion, or both, may be necrotic and invaded by hemocytes. As infection progresses, crabs become sluggish, refuse to eat, and often suffer progressive paralysis. Hemolymph does not gel. When an infected crab is held out of water, the posterior pair of legs may tremble while the others hang limply. With electron microscopy, the cytoplasmic inclusions are seen to be paracrystalline arrays of virus particles (Figure 7). The virions of RLV are icosahedral and about 55 to 60 nm (Johnson 1977a, b).

A rhabdo-like virus (RhVA) was also present in tissues of crabs infected with RLV and examined by electron microscopy (Johnson 1983, 1984). This virus, which is described below, apparently acts synergistically with RLV to cause paralysis. Other viruses may occur in crabs infected with RLV, including another rhabdo-like virus (EHV) and the baculoviruses, Baculo-A and Baculo-B.

Injection of hemolymph infected with RLV+RhVA into healthy crabs causes disease that can kill some crabs, particularly pre- and postmolt animals, in as little as 3 to 4 days. RLV+RhVA probably enter through the gut epithelia in nature because these viruses can be transmitted orally by feeding of infected tissues. In this case, first deaths in intermolt crabs may not occur until 12 days after feeding (Johnson 1978, 1983). In the stressful environment of a shedding tank, the viruses possibly also enter through wounds or by other routes.

Prevalence of RLV+RhVA infection in natural populations is unknown. Crabs diagnosed as being infected usually had been held for a few to many days in the laboratory before exhibiting signs of infection, and transmission may have been occurring in the laboratory tanks.

Diagnosis of RLV+RhVA infection depends on demonstration of the viruses by electron microscopy of tissues of sick crabs that come from groups with signs of sluggishness, paralysis, nongelling hemolymph, and with typical lesions in the nervous system and/or hemocytes and hemopoietic tissue. Electron microscopy need be performed only on one or two crabs in such groups for reasonably firm diagnosis of RLV+RhVA as cause of the morbidity or mortality, if bacterial disease has been ruled out as a major factor.

Rhabdo-like Virus A. The smallest rhabdo-like virus, Rhabdo-like virus A (RhVA), occurs in populations of blue crabs from the Atlantic and Gulf coasts and is probably ubiquitous in the blue crab. Jahromi (1977), Johnson (1978), and Yudin and Clark (1978) found RhVA in crabs stressed by culture conditions, infections with other viruses, and eyestalk ablation, respectively. RhVA is either bacilliform with rounded ends and 20 to 30 × 110 to 170 nm, or flexuous, the same diameter, and up to 600 nm in length

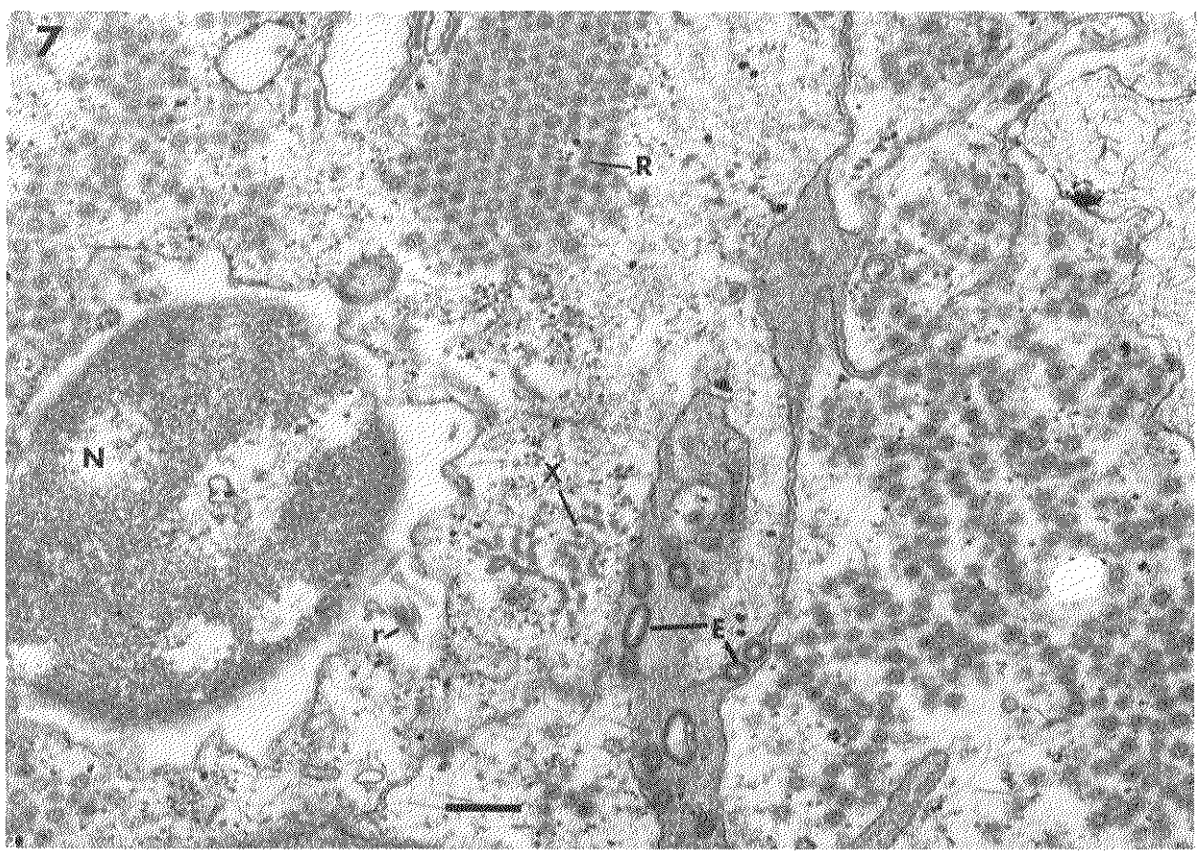


Figure 7. Electron micrograph of cells jointly infected with RLV, RhVA, and EHV. Bar = 310 nm. E, mature extracellular virions of EHV associated with basal laminas; N, nucleus; R, RLV; r, RhVA; X, intracellular nucleocapsids of EHV.

(Figure 7). It buds into the endoplasmic reticulum, and infects many different tissues. It occurs regularly in glial cells of ganglia and the larger nerves, and is common in hemocytes, hemopoietic tissue, connective tissue, and various epithelia except those of the gut and antennal gland. It does not infect striated muscle and may not infect the Y-organ (Johnson 1978, 1983), but does infect the mandibular gland (Yudin and Clark 1978, 1979). RhVA occurred with one or more other viruses in crabs whose tissues were examined by electron microscopy by Johnson (1978, 1983). As stated earlier, sick crabs infected with RLV probably always have an associated infection with RhVA, and these two viruses are thought jointly responsible for the glial necrosis typical of the mixed infection.

RhVA cannot be identified by examination of tissues with the light microscope and proof of its presence in tissues rests upon examination with the electron microscope.

Enveloped Helical Virus. A second and larger rhabdo-like virus is the Enveloped Helical Virus (EHV) reported by Johnson and Farley (1980). EHV infects crabs in Chesapeake Bay and its tributaries. It also occurred in crabs from Chincoteague Bay and the eastern coast of Florida that had been used in various attempts to transmit viruses. The virions are either ovoid or somewhat rod-like. Ovoid forms are about 105 × 194 nm, and rod-like virions of the same diameter are up to 300 nm long. There are projections on the outer surface of the enveloping membrane. Mature virions form by budding through the plasma membrane and are found only extracellularly. They are often associated with basal laminas or lie between the basal lamina and the plasma membrane (Figure 7). Granular virogenic stromata in the cytoplasm of infected cells produce sinuous helical nucleocapsids (Figure 7). Virus was seen budding from hemocytes and hemopoietic-tissue cells, and was associated with the basal lamina of certain connective-tissue cells. Because presence of EHV (like that of RhVA) cannot be distinguished by examination of tissues with the light microscope and because it has been found only with other viruses, effect of EHV on the host cannot be appraised.

Rhabdo-like Virus B. Rhabdo-like Virus B (RhVB) is known only from the report by Yudin and Clark (1978), who discovered it extracellularly beneath the basal lamina of the mandibular organ. The ovoid virions were said to be 50 to 70 × 100 to 170 nm, and the enveloping membrane had surface projections. RhVB occurred in crabs from the Gulf of Mexico, was found in approximately 3% of 60 mandibular organs examined by electron microscopy and, in one case, was associated with RhVA. Crabs with RhVB infection appeared normal.

Because EHV and RhVB are strikingly similar in all but reported size, it is possible that they represent a single species of virus and that differences in measuring techniques may be responsible for the supposed differences in size.

Chesapeake Bay Virus. The picorna-like virus of the blue crab, Chesapeake Bay Virus (CBV), was discovered in a captive group of young crabs collected from Tangier Sound, Chesapeake Bay (Johnson 1978, 1983). It has not been seen by electron microscopy in tissues of wild crabs, but lesions suggestive of CBV disease are sometimes seen with the light microscope in tissues of crabs from other parts of Chesapeake Bay and from Assawoman Bay, DE.

CBV is associated mainly with tissues of ectodermal origin. It infects the cytoplasm of neurosecretory and other nervous cells (but not the glia), epidermis, gill and bladder epithelia, and epithelia of the fore- and hindgut. Hemopoietic tissue and hemocytes may be infected but many crabs with CBV do not have such involvement. Infection is often focal, with patently infected cells, recognizable with the light microscope, occurring in limited groups. Infected cells are usually hypertrophied and the cytoplasm is filled with Feulgen-negative, homogeneous material consisting almost entirely of virus (Figure 8). Although infection is often focal, the gill epithelium may be almost completely infected and destruction of the entire retina is common. The virions are approximately 30 nm in diameter, sometimes are in paracrystalline array, and may be associated with membranes.

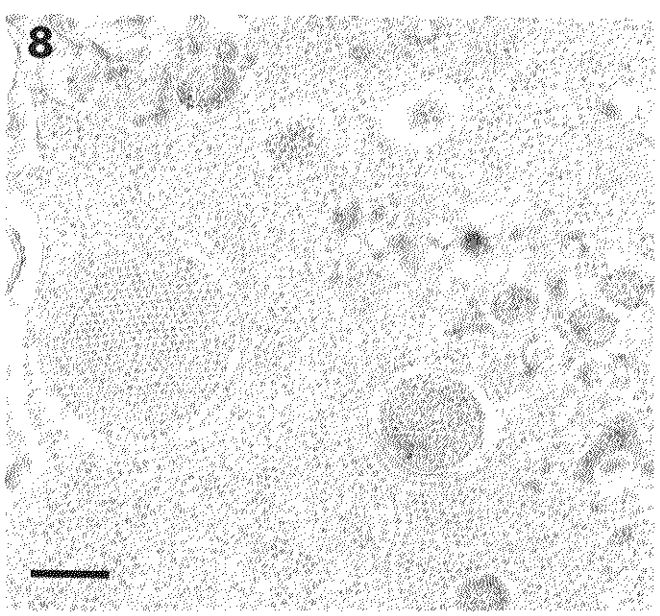


Figure 8. Electron micrograph of CBV. Bar = 310 nm.

Infected crabs behave abnormally. They may assume a head-down position, turn onto their backs, swim in a disoriented manner and move erratically. Blindness is common. One or more of these signs may be present for a month before death and entire course of the disease takes up to 2 months. Because tissues attacked differ among crabs and infection tends to be focal, prolonged disease may be due to vital centers not being destroyed until late in disease. Death could be due to respiratory insufficiency or to destruction of vital nervous centers and neurosecretory cells.

Preliminary diagnosis of CBV disease can be made on the basis of behavioral signs and presence in target tissues of characteristically hypertrophied cells with dense Feulgen-negative cytoplasm. Final diagnosis depends on demonstration of virus by electron microscopy.

IMPLICATIONS OF VIRAL INFECTION TO SHEDDING OPERATIONS

Couch (1974) and Couch and Courtney (1977) have shown experimentally that the stress of crowding or exposure to certain chemicals can increase prevalence and intensity of a viral disease in captive penaeid shrimp. Presumably, the same process could occur in crabs being held in the crowded environments of shedding tanks.

Viral infections in shedding-tank crabs could come from two sources: preexisting infection and infection acquired in the tank. Casual evidence suggests that viral disease can be epizootic in nature at certain times in certain crab populations. Premolt crabs in early or latent stages of infection, taken from a population undergoing an epizootic, would offer multiple sources of infection. The epizootic could be continued by transmission within the shedding tank, particularly among white-sign crabs (molt stage D_1-D_2), which might be expected to stay at least a week in the tanks before molting.

Viruses causing rapid death would appear most likely to be involved in shedding-tank mortalities. RLV+RhVA is a combination that fits this criterion. They kill rapidly and damage to nervous tissue may be the reason. In premolt crabs, such damage would be particularly grave because the events that take place during that stressful time are under nervous control. In an experimental series of crabs injected with RLV+RhVA, pre- and postmolt animals were the first to succumb to viral infection. Crabs that died on post-injection days 3–7 were either pre- or postmolt; deaths in intermolt crabs did not occur until post-injection day 11 (Johnson, unpublished data).

Necrosis in glia of the nervous sytem had occurred in dead and moribund crabs taken from two shedding-tank mortalities I studied. In the first case, RLV+RhVA, plus EHV, were found by electron microscopy in tissues of one of the crabs and presumably other animals with similar lesions were also virus infected. In the second mortality, electron microscopy was not performed, but lesions in the nervous system of affected crabs were similar to the above and, tentatively, are considered to have been due to infection with RLV+RhVA (Johnson, unpublished data).

Evidence, although fragmentary, suggests that viral infection may be a cause of shedding-tank mortality and warrants further investigation.

REFERENCES CITED

Bang, F. B. 1971. Transmissible disease, probably viral in origin, affecting the amebocytes of the European shore crab, *Carcinus maenas*. *Infect. Immun.* 3:617–623.

Bazin, F., P. Monsarrat, J. R. Bonami, G. Croizier, G. Meynadier, J. M. Quiot and C. Vago. 1974. Particules virales de type baculovirus observées chez le crabe *Carcinus maenas*. *Rev. Trav. Inst. Pêches Marit.* 38:205–208.

Bonami, J.-R. 1976. Viruses from crustaceans and annelids: our state of knowledge. *Proc. 1st Int. Colloq. Invertebr. Pathol.* 1:20–23.

_____ and C. Vago. 1971. A virus of a new type pathogenic to Crustacea. *Experientia* 27:1363–1364.

Chassard-Bouchaud, C. and M. Hubert. 1975. Sur l'existence de vésicles de réticulum endoplasmique lisse dans l'organe Y de *Carcinus maenas* L. (Crustacé Décapode). *C. R. Acad. Sci. (D)* 281:707–709.

Couch, J. A. 1974. An enzootic nuclear polyhedrosis virus of pink shrimp: ultrastructure, prevalence, and enhancement. *J. Invertebr. Pathol.* 24:311–331.

_____ and L. Courtney. 1977. Interaction of chemical pollutants and virus in a crustacean: a novel bioassay system. *Ann. N. Y. Acad. Sci.* 298:497–504.

Jahromi, S. S. 1977. Occurrence of Rhabdovirus-like particles in the blue crab, *Callinectes sapidus*. *J. Gen. Virol.* 36:485–494.

Johnson, P. T. 1976a. A herpeslike virus from the blue crab, *Callinectes sapidus*. *J. Invertebr. Pathol.* 27:419–420.

_____ . 1976b. A baculovirus from the blue crab, *Callinectes sapidus*. *Proc. 1st Int. Colloq. Invertebr. Pathol.* 1:24.

_____ . 1977a. A viral disease of the blue crab, *Callinectes sapidus*: histopathology and differential diagnosis. *J. Invertebr. Pathol.* 29:201–209.

_____ . 1977b. Reovirus-like virus of blue crabs. Sindermann, C. J. ed. *Disease Diagnosis and Control in North American Marine Aquaculture*. New York: Elsevier Sci. Publ. Co. 103–105.

_____ . 1978. Viral diseases of the blue crab, *Callinectes sapidus*. *Mar. Fish. Rev.* 40(10):13–15.

_____ . 1983. Diseases caused by viruses, rickettsiae, bacteria, and fungi. Provenzano, A. J. ed. *The Biology of Crustacea*. New York: Academic Press. Vol. 6:1–78.

_____ . 1984. Viral diseases of marine invertebrates. *Helgol. Meeresunters.* 37:65–98.

_____ and J. E. Bodammer. 1975. A disease of the blue crab, *Callinectes sapidus*, of possible viral etiology. *J. Invertebr. Pathol.* 26:141–143.

Johnson, P. T. and C. A. Farley. 1980. A new enveloped helical virus from the blue crab, *Callinectes sapidus*. *J. Invertebr. Pathol.* 35:90–92.

Kuris, A. M., G. O. Poinar, Jr., R. Hess and T. J. Morris. 1979. Virus particles in an internal parasite, *Portunion conformis* (Crustacea: Isopoda: Entoniscidae), and its marine crab host, *Hemigrapsus oregonensis*. *J. Invertebr. Pathol.* 34:26–31.

Lightner, D. V. 1983. Diseases of cultured shrimp. McVey, J. P. ed. *Mariculture*. Boca Raton, Florida: CRC Press; 289–320.

_____ and R. M. Redman. 1981. A baculovirus-caused disease of the penaeid shrimp, *Penaeus monodon*. *J. Invertebr. Pathol.* 38:299–302.

_____ . 1985. A parvo-like virus disease of penaeid shrimp. *J. Invertebr. Pathol.* 45:47–53.

_____ and T. A. Bell. 1983. Infectious hypodermal and hematopoietic necrosis (IHHN), a newly recognized virus disease of penaeid shrimp. *J. Invertebr. Pathol.* 42:62–70.

Pappalardo, R. and J.-R. Bonami. 1979. Infection des Crustacés marins due à un virus de type nouveau apparenté aux *Baculovirus*. *C. R. Acad. Sci. (D)* 288:535–537.

Payen, G. G. and J.-R. Bonami. 1979. Mise en evidence de particules d'allure virale associées aux noyaux des cellules mesodermiques

de la zone germinative testiculaire du crabe *Rhithropanopeus harrisii* (Gould) (Brachyoure, Xanthide). *Rev. Trav. Inst. Pêches Marit.* 43:361–365.

Sano, T., T. Nishimura, K. Oguma, K. Momoyama and N. Takeno. 1981. *Baculovirus* infection of cultured Kuruma shrimp, *Penaeus japonicus* in Japan. *Fish Pathol.* 15:186–191.

Vago, C. 1966. A virus disease in Crustacea. *Nature* 209:1290.

Yudin, A. I. and W. H. Clark, Jr. 1978. Two viruslike particles found in the ecdysial gland of the blue crab, *Callinectes sapidus*. *J. Invertebr. Pathol.* 32:219–221.

_____ . 1979. A description of rhabdovirus-like particles in the mandibular gland of the blue crab, *Callinectes sapidus*. *J. Invertebr. Pathol.* 33:133–147.

Zerbib, C., N. Andrieux and J. Berreur-Bonnenfant. 1975. Données préliminaires sur l'ultrastructure de la glande de mue (organe Y) chez le Crabe *Carcinus mediterraneus* sain et parasité par *Sacculina carcini*. *C. R. Acad. Sci. (D)* 281:1167–1169.

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INVOLVEMENT OF *VIBRIO* SPP. IN SOFT CRAB MORTALITY

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Soft-shell blue crabs are a profitable seafood product which has not been fully exploited in North Carolina. However, new shedding facilities are being established and more North Carolina residents are entering the industry (Caudle 1983). Basically, the business involves holding premolt hard-shell crabs in tanks until they shed into soft-shell crabs which can be removed, packaged, and sold at a profit. In addition to the logistic problems associated with establishing and maintaining shedding tanks, finding a source of premolt crabs, and marketing the soft-shell crabs, the problem of crab mortality in the holding tanks exists (Haefner and Garten 1974). The exact mortality rates in shedding tanks are poorly documented and varied with the individual shedder and the conditions of their facilities. Published reports have claimed that mortality rates can be as high as 50 to 80% (Krantz et al. 1969, Haefner and Garten 1974). Mortality rates approaching this level create obvious financial problems for the industry.

Traditionally, shedding-tank mortalities have been assumed to be due largely to microbial infections. Usually, these infections are believed to be the result of microorganisms introduced and encouraged in their growth by poor handling procedures and/or poor water quality. In a series of studies begun in the laboratory of Dr. R. R. Colwell at the University of Maryland, it was established that bacteria exist as chronic infections in the hemolymph (i.e., bacteremias) of most normal, apparently healthy blue crabs. These bacteria can multiply with the proper stimulation, and cause a fatal septicemias (Krantz et al. 1969, Sizemore et al. 1975, Tubiash et al. 1975). In response to doubts expressed by some blue crab biologists concerning bacteremias (Johnson 1976), we have documented that individual crabs sampled 4 minutes after capture in star traps contain bacteremias (Welsh and Sizemore 1985). The implication of these data on blue crab mortality studies is significant. Most studies have assumed that mortalities are due to acute infections caused by newly introduced pathogens and have attempted to develop a defense strategy based on that assumption (e.g., Oesterling 1982). If healthy premolt crabs already possess the bacterial infections capable of causing mortality, then the strategy to reduce mortality should emphasize reducing the stimuli which initiate the "break out" of the preexisting infections. This approach is novel and may lead to ways to significantly reduce mortality rates. Furthermore, because many of the bacteria found in chronic crab bacteremias are members of the genus *Vibrio*, which contains human as well as crab pathogens (Sizemore et al. 1975, Davis and Sizemore 1982), maintaining low bacteremia levels will not only reduce mortality but should improve the quality of meat of the crabs which shed normally.

To test this hypothesis, a Sea Grant-sponsored project has been developed to study bacteremias in molting blue crabs. Wooden shedding tanks designed to resemble those used by commercial shedders (e.g., Wescott 1984) have been constructed and modified to permit experimental manipulation of environmental parameters. In these tanks, we have shed crabs during spring–fall 1984 while carefully recording data on crab mortalities and environmental parameters.

Crab mortalities varied between 8 to 80% during various shedding experiments at the facility. Normally there was a high mortality rate (approaching 75% in the majority of the experiments) which apparently was due to the experimental conditions and the poor quality of many of the crabs used. The commercial crab shedders surveyed had poor documentation, but generally reported crab mortalities between 10 and 30%. Data are continuing to accumulate, but it is obvious that the mortality rate is a significant problem for shedders. Furthermore, variations in mortality rates among shedders suggest that some crabbers may be using optimal conditions, which reduce mortalities. An attempt is being made to identify these conditions.

In these studies, most mortality occurred during the first two days after the crabs were placed in the shedding tank. Thus, newly arrived crabs are assumed to be stressed and should be handled gently. Identifying the exact nature of the stress is a long-term goal of this study.

It has also been documented that white-line and intermolt crabs have a significantly higher mortality rate (65% versus 20%) than crabs closer to molting (pink-line or red-line crabs) in the shedding tanks. It is recommended that shedders avoid using intermolt crabs whenever possible.

No clear relationship has been found between the total number of bacteria in crab blood and successful survival of the molting crab. Taxonomic identification of the individual bacteria is underway to determine if a rise in a certain type of bacteria in the blood is correlated with mortality.

Bacteria were associated with all the crabs studied and the majority of the crabs (91%) had bacteria in their

blood. Most of the external bacteria appeared to be harmless but 85% of the bacteria in the blood were considered as potential pathogens because they belong to the genus *Vibrio*. Members of this genus cause a number of human diseases and can infect marine animals, such as crabs, as well. Most of the *Vibrio* strains were identified as members of two groups: the *Vibrio parahaemolyticus/vulnificus* group and the sucrose-positive *Vibrio cholerae*-like group. Both of these groups are known to contain human pathogens and several potential bacterial pathogens have been isolated from dying crabs. Some of these isolates appear to be correlated with small "epidemics" in the study shedding facilities. Infectivity and taxonomic studies are being carried out with these isolates. Identification, characterization, and quantification of these bacteria are essential before practical control of crab mortalities can be initiated.

If these bacteria prove to be crab pathogens, then the known characteristics of these bacteria may be taken advantage of to control them. For example, the *Vibrio parahaemolyticus/vulnificus* group, which appears to be a likely group of crab pathogens, requires salt for survival. Blue crabs can survive in salinities lower than these bacteria can tolerate. Thus, to eliminate this type of bacteria, molting crabs could be shed in low-salinity water. Testing of this hypothesis is in process and an attempt to find other practical ways to use the characteristics of the bacteria to control bacterial diseases in crabs is underway.

Mortality in crab-shedding tanks is a severe economic problem that discourages entry into and/or continuation in the shedding business. Reduction and/or establishment of an acceptable stable mortality rate would result in a more profitable and stable business for the producer and a more dependable product for the consumer. This project addresses the problem of shedding mortality and attempts to find ways to control bacterially induced crab mortality.

REFERENCES CITED

Caudle, N. 1983. Crabbers turn soft-shells into hard cash. *Coast Watch*. Available from: North Carolina Sea Grant.

Davis, J. W. and R. K. Sizemore. 1982. The incidence of *Vibrio* species associated with blue crabs (*Callinectes sapidus*) collected from Galveston Bay, Texas. *Appl. Environ. Microbiol.* 43:1092–1097.

Haefner, P. A. and D. Garten. 1974. Methods of handling and shedding blue crabs, *Callinectes sapidus*. Marine Resource Advisory Series No. 8, Virginia Sea Grant Program.

Johnson, P. T. 1976. Bacterial infection in the blue crab, *Callinectes sapidus:* course of infection and histopathology. *J. Invertebr. Pathol.* 28:25–36.

Krantz, G. E., R. R. Colwell and E. Lovelace. 1969. *Vibrio parahaemolyticus* from blue crab *Callinectes sapidus* in Chesapeake Bay. *Science* 164:1286–1287.

Oesterling, M. J. 1982. Mortalities in the soft crab industry: sources and solution. Marine Resource Report No. 82–6, Virginia Sea Grant Program.

Sizemore, R. K., R. R. Colwell, H. S. Tubiash and T. E. Lovelace. 1975. Bacterial flora of the hemolymph of the blue crab, *Callinectes sapidus:* numerial taxonomy. *Appl. Microbiol.* 29:393–399.

Tubiash, H. S., R. K. Sizemore and R. R. Colwell. 1975. Bacterial flora of the hemolymph of the blue crab, *Callinectes sapidus:* most probable numbers. *Appl. Microbiol.* 29:388–392.

Welsh, P. C. and R. K. Sizemore. 1985. Incidence of bacteremia in unstressed populations of the blue crab, *Callinectes sapidus. Appl. Environ. Microbiol.* 50:420–425.

Wescott, W. 1984. *A Guide to Soft Shell Crabbing.* Univ. of North Carolina Sea Grant College Publication UNC–SG–84–01.

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985, 23–30.

THE CRUSTACEAN MOLT CYCLE AND HORMONAL REGULATION: ITS IMPORTANCE IN SOFT SHELL BLUE CRAB PRODUCTION

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INTRODUCTION

Crustaceans are covered by a rigid exoskeleton, or cuticle, which consists of a chitin-protein complex impregnated by calcium. This integument acts as a protective barrier to the environment as well as a skeletal-support system. For growth to occur the cuticle must be shed. Ecdysis, the shedding of the old exoskeleton, is done periodically throughout the life of most crustaceans.

The period from one ecdysis to the next one is known as the molt cycle. The events which take place as the molt cycle progresses occur primarily in the integument although almost all organs undergo some change. In this paper we present a review of the molt-cycle events and the manner in which they are controlled by hormones for crustaceans in general. Where possible, we will mention points that are characteristic of blue crabs in particular. Our goal is to acquaint the person who is interested in soft shell blue crab production with the basic background information so that he or she will have a fundamental working knowledge of the molting process.

THE MOLT CYCLE

The first successful systematic approach to understanding the molt cycle was developed by Pierre Drach (1939, 1944). Drach divided the molt cycle into five stages, labeled A–E, each of which can be further subdivided (Figure 1). The utility of this system has been found by later workers to be such that it can be applied to any crustacean with slight modification and additions to make it more complete and more accurate for that organism (Skinner 1962; Drach and Tchernigovtzeff 1967; Stevenson 1968, 1972; Freeman and Bartell 1975; Freeman and Costlow 1980). The criteria listed below for each stage refer only to the integument (epidermis plus exoskeleton).

Postmolt (Stages A and B)

Immediately after ecdysis the exoskeleton consists of a thin epicuticle and the complete but unhardened exocuticle (Stevenson 1968; Hegdahl et al. 1977b, c; Roer and Dillaman 1984). The cuticle is soft, pliable and can be stretched. The stretchability of the cuticle permits, in part, the expansion of the integument as the animal swells upon uptake of water at ecdysis. Hardening of the cuticle by tanning (Travis 1957, Stevenson 1968) and/or by calcification (Roer and Dillaman 1984) begins shortly after ecdysis. The calcium reaches the epicuticle and the exocuticle via the pore canals (Travis 1957). Calcification effectively halts expansion of the cuticle and permits muscular activity.

Dendinger and Alterman (1983) found that the extensability (percent elongation) of *Callinectes sapidus* Rathbun cuticle rose during the first 3 to 4 hours after ecdysis (Stage A). It then dropped rapidly over the next 8 hours and continued to decline gradually for the next 60 hours. The immediate rise was correlated with an increase in the chitin and protein content of the cuticle but not with the calcium content. They further demonstrated that selective removal of calcium (96%) by EDTA resulted in a 200% increase in the percent elongation and tensile strength of the cuticle of a 24-hour postmolt crab while removal of protein or chitin resulted in a reduction in percent elongation and tensile strength.

Completion of the exoskeleton begins by the secretion of the endocuticle (Stage B). The endocuticle is produced one layer at a time and this production may follow some daily rate of secretion (Travis 1957). The endocuticle has thicker lamellae, more lamellae, and grows to a thickness that is greater than the exocuticle (Figure 2) (Hegdahl et al. 1977a). As each layer is secreted calcium salts are secreted into the chitin-protein complex via the pore canals of the epidermal cells (Arsenault et al. 1984, Roer and Dillaman 1984, Travis 1957). The calcium will precipitate and further harden the endocuticle as it is made, as well as harden the previously formed exocuticle.

The thickness and dry weight of *C. sapidus* cuticle increase during the first 30 days of the molt cycle (Price-Sheets and Dendinger 1983). This indicates that there is a gradual and continuous secretion of endocuticle lamellae. Analysis of the cuticular components showed that the percentage dry weight of chitin and protein in the cuticle fell during the first day and then stabilized at 10 to 11% after day 2 (Vigh and Dendinger 1982), although the absolute amount of each component continued to increase throughout the 10-day study period. Calcium increased dramatically during the first 2 days and then showed a slower rise which followed the chitin-protein levels for the rest of the period (Vigh and Dendinger 1982, Price-Sheets and Dendinger 1983). These findings suggest that the initial (day 1) events of postmolt consist of stretching followed by rapid calcification of the exocuticle and that the secretion of the endocuticular lamellae occurs for at

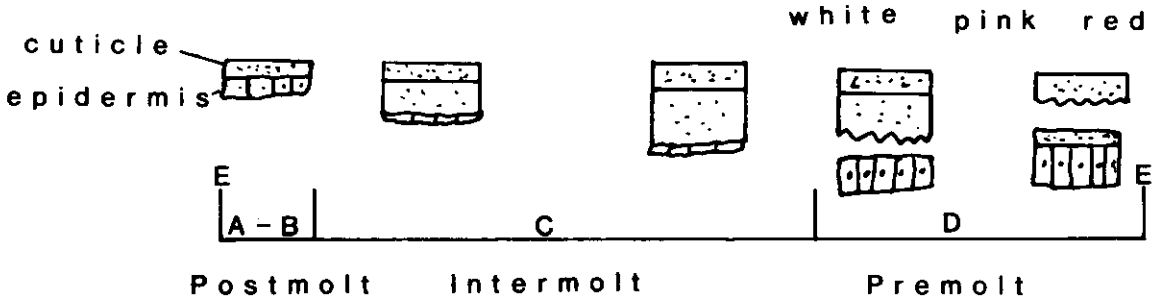

Figure 1. The molt cycle for a generalized crustacean. Ecdysis (shedding) occurs at stage E. The crab is in the soft-shell condition during stage A. Secretion of the endocuticle begins during stage B and continues on into stage C. Calcification takes place as the cuticular lamellae are secreted. The epidermal cells decrease in size during stage C. Premolt (stage D) begins at apolysis (substage D_0) and the endocuticle is enzymatically digested. The new cuticle (epicuticle and exocuticle) is secreted under the old one.

least 10 and, possibly, 30 days. The endocuticle lamellae are calcified as they are made. Thus, the percent calcium, percent protein, and percent chitin all should rise at equivalent rates. This has been shown to be true for blue crabs (Vigh and Dendinger 1982).

Postmolt is a relatively short phase of the molt cycle, lasting several hours to several days, depending on the species and size of the crustacean. The epidermal cells undergo a gradual decrease in size during postmolt. By the end of the postmolt period, the exoskeleton is almost complete and the epidermal cells are squamous (Travis 1957, Skinner 1962, Freeman and Bartell 1975, Freeman and Costlow 1980, Roer and Dillaman 1984). The smaller size of the epidermal cells reflects the lower synthetic activity of the cells.

Intermolt (Stage C)

The intermolt phase is the most variable in duration. Fewer changes occur in the integument although cuticular components undergo some turnover and maintenance (Roer and Dillaman 1984). The innermost layers of the endocuticle and the nonprotein membranous layer are secreted during this period. In addition, most of the internal tissue growth takes place during this phase (Passano 1960). Nutrient stores are sequestered in the hepatopancreas and all reproductive activity in males occurs while the crab is in intermolt (Adiyodi and Adiyodi 1970, Quakenbush and Herrnkind 1981). Female blue crabs mate while in postmolt and carry the eggs during intermolt.

Intermolt begins at the end of stage B in rapidly molting crustaceans that have diecdysial molt cycles (Drach and Tchernigovtzeff 1967, Freeman and Bartell 1975). In these animals the intermolt period is very short, less than a week. In crustaceans such as the blue crab, which molts less frequently, the postmolt period continues into stage C (Roer and Dillaman 1984) indicating that the construction of the exoskeleton continues in stage C. External changes during this period, however, have not been defined and, thus, the criteria for substages C_1, C_2, and C_3 are based on cuticular rigidity. Substage C_4 is defined as the point when endocuticular growth halts and the thin membraneous layer (Figure 2) is secreted (Passano 1960). No change occurs in the cuticle after this point.

The duration of substage C_4 varies but may last for the rest of the life of the crab. In this case it is termed C_{4T} (= terminal molt) (Passano 1960, Drach and Tchernigovtzeff 1967). This crab will not molt again. Female blue crabs enter substage C_{4T} after the molt to maturity. During this time they will carry the eggs.

Male blue crabs continue to molt throughout life. Little is known of the duration of any of the intermolt stages in these crabs. Because cuticular growth has been shown to continue for 30 days (Price-Sheets and Dendinger 1983) and the premolt period, as defined by paddle signs, can last 10 to 14 days, then the C_4 substage must be relatively short, lasting several days in a male or juvenile female (carapace width $>$ 120 mm) crab. Tagatz (1968) has shown that crabs of this size have a molt cycle duration of approximately 30 to 50 days in warmer months. Clearly there is a need for a well defined set of criteria for dividing the post- and intermolt periods of blue crabs into measurable substages that does not require destructive sampling.

Premolt (Stage D)

The premolt phase is a period of active synthesis and resorption in the integument and prepares the crab for the next ecdysis (Figure 1). The first event is apolysis (substage D_0), the separation of the epidermis from the exoskeleton. The epidermal cells enlarge at this time as they develop the intracellular machinery necessary to synthesize the new cuticle.

The enzymatic digestion of the old cuticle continues throughout the premolt period. As the old cuticle is digested, calcium, protein and chitin are resorbed and reused in the secretion of the new exoskeleton (Roer 1980). The percentage of the old cuticle resorbed varies among species but includes only the membraneous and endocuticular layers. The exocuticle is not resorbed and remains as a

barrier to the exterior environment and skeletal support for movement during the later phase of premolt.

Immediately after apolysis the epidermis begins secretion of the epicuticle (substage D_1). This tanned lipid-protein layer is secreted as lamellae but is very thin and not calcified (Hegdahl et al. 1977c). The chemical nature of this layer accounts for the protection of the exocuticle from the enzymes digesting the old cuticle and, after molting, it will be the the primary chemical barrier to the environment (Hegdahl et al. 1977c, Stevenson 1968, Roer and Dillaman 1984). Following secretion of the epicuticle, the exocuticle is secreted (substage D_2) (Travis 1955). This part of the cuticle is made up of chitin and protein and is secreted in layers (Hegdahl et al. 1977a, Roer and Dillaman 1984), but is not hardened by calcification or tanning during the premolt period. Most of the synthesis of this layer occurs during substage D_2. It is finished shortly before ecdysis.

Most crustaceans remain mobile right up to the time of ecdysis, even though the cuticular changes are continuing. They are able to do so because the tendonal cells with tonofibrillae (Dennel 1960, Koulish 1973) remain attached to the old exoskeleton (Figure 3). These cells separate from the old exoskeleton during the last phase of the premolt period (substage D_3). Meanwhile, new connections are established with the new cuticle.

Growth in the epidermis occurs by cell division. Although the exact point in the molt cycle when the divisions happen does not appear to be the same in all crustaceans, most decapods show a period of cell division during early premolt (substages D_1–D_2) (Tchernigovtzeff 1965). Histological observations in crabs and crayfish near the end of the premolt stage show that the epidermis and new cuticle are folded as ecdysis approaches. The folding accounts for the extra area in the integument which was generated through cell division. Wittig and Stevenson (1975) have demonstrated that DNA synthesis takes place in late intermolt and early premolt. This correlates with the onset of cell replication which occurs immediately after this time.

In crustaceans having a clear exoskeleton, the stages of the premolt period can be identified by changes in setated regions of the exoskeleton such as the uropods, pleopods and antennae (Drach 1944; Drach and Tchernigovtzeff 1967, Freeman and Bartell 1975, Freeman and Costlow 1980). Premolt stages can be determined in heavily calcified crustaceans, but with less accuracy. Here, small appendages must be removed for microscopic observation (Drach and Tchernigovtzeff 1967). In blue crabs the change in appearance at the edge of the swimmeret (paddle signs) can be used to determine the time to ecdysis in animals that have entered premolt (Perry et al. 1982) (Figure 4). Although the white sign seen around the edge of the paddle indicates that apolysis has occurred, it does not indicate what other cellular or integumental events have begun. Moreover, it is possible that the premolt period has already begun prior to

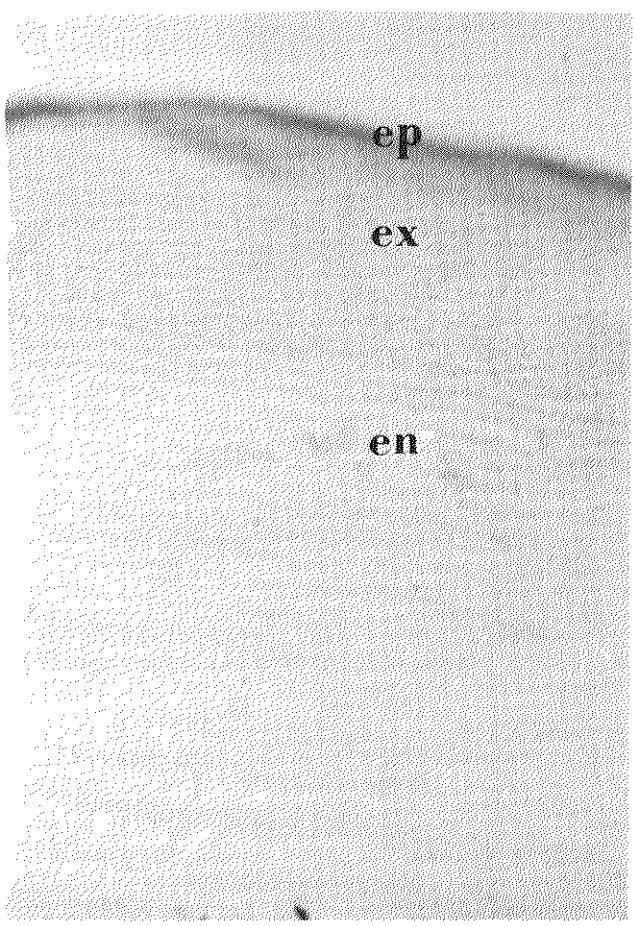

Figure 2. Photograph of the cuticle of an intermolt blue crab. The three primary layers of the cuticle (epicuticle, ep; exocuticle, ex; endocuticle, en) can be seen (X1500).

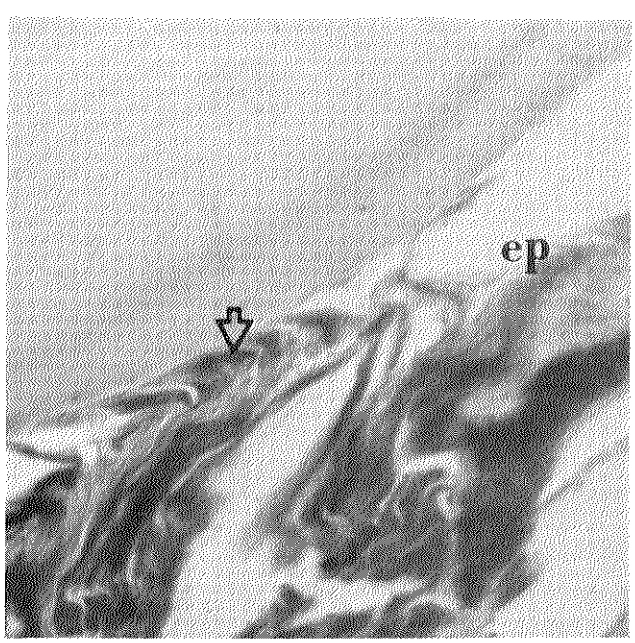

Figure 3. Micrograph of the cuticle of the dorsal carapace of *Callinectes sapidus* during premolt. The tendonal cells (arrow) attach the cuticle to the underlying muscle by tonofibrillae. The adjacent epidermis (ep) has undergone apolysis (X1500).

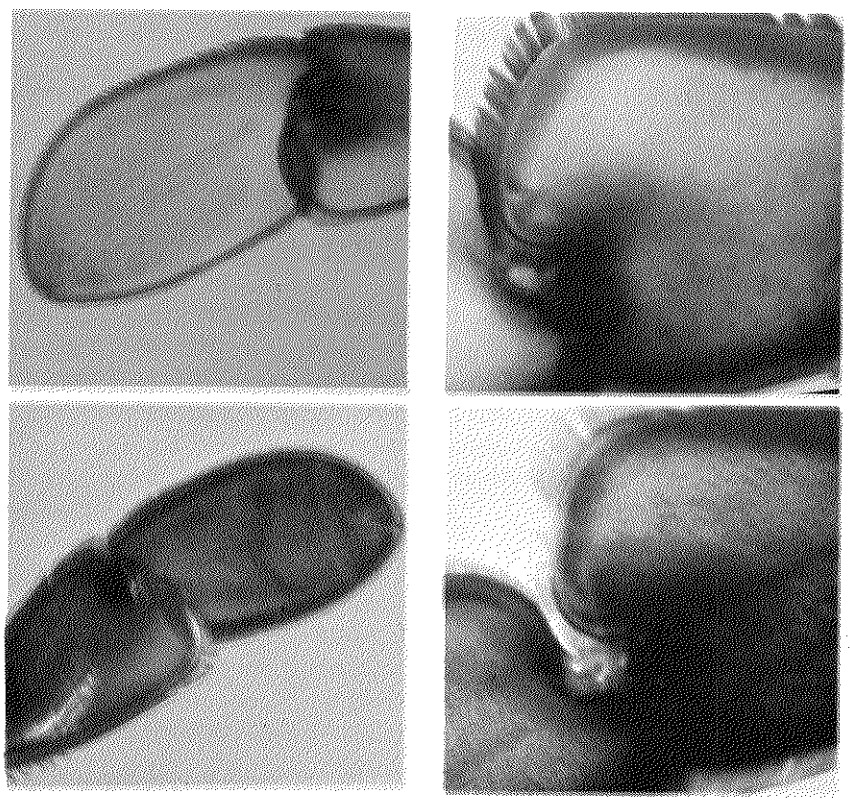

Figure 4. The appearance at the edge of the paddle (swimmeret) of a blue crab during intermolt (A), and during premolt phases: white (B). pink (C), and red (D). Crabs in the red condition will molt in 1 to 3 days.

the time that the white sign is visible. The pink sign (3 to 5 days to molt) and red sign (1 to 3 days to molt) are also useful in designating temporal progress through premolt. Both the pink and red signs probably take place during late premolt (substages D_2, D_3) (Figure 4).

Ecdysis (Stage E)

Ecdysis begins by the uptake of water across the walls of the gut or across the gill surface (Passano 1960). By whatever means, this rapid absorption of water increases the hemolymph volume and, thus, places pressure on the exoskeleton. The increased internal pressure causes the rupture of the old exoskeleton along particular regions of the cuticle. These regions of the exoskeleton, called epimeral sutures, undergo greater enzymatic digestion than do neighboring areas during premolt. In the blue crab, the most noticeable regions are along the dorsal carapace in the thorax-abdomen junction, the merus, and the face (Perry et al. 1982). Upon rupture of this suture, the crab can begin to back out of the old exoskeleton. The enhanced hydrostatic pressure also causes the expansion (unfolding plus stretching) of the new cuticle. This not only aids the escape of the crab from the old cuticle but also augments the increase in size of the animal before hardening of the

cuticle begins in stage A. Stage E is a very short period, usually lasting less than an hour. During this phase, the crab cannot move, eat or respire, and is vulnerable to attack by predators or other blue crabs. For this reason, the crab usually seeks a hiding place in which to molt.

Extended Substage D_0

Most researchers have assumed, based on available staging methods, that substage D_0 was very short in duration and would be passed through quickly. Recent findings have shown, however, that some crustaceans actually enter premolt much earlier than expected and remain in substage D_0 for a longer period of time. In this case, stage C is reduced in duration. It is not known if this is true of large decapods such as the blue crab.

External Molt Regulation

Water temperature and nutrition both affect the molting rate. Tagatz (1968) has shown that the frequency of molting in blue crabs is higher in summer than in winter. An optimum water temperature for molting appears to be between 25 and 28°C. Above the optimum temperature, the physiological processes appear to accelerate to the extent that molting takes place but with less growth. As the water temperature drops below 18°C, however, the molting rate decreases as the metabolism of the crab is reduced. Thus, most large decapod crustaceans molt and grow more during the summer when water temperatures approach optimum.

Many studies have been done to demonstrate the effect of food quality and quantity on growth in crustaceans (Nakatani and Otsu 1981, Hartnoll 1982). The need for this information in aquaculture is clear because proper diet must be defined for optimum growth. To date, no such data have been forthcoming for blue crabs.

Growth

The growth rate, or linear increase in dimension over one molt cycle, is probably genetically controlled, although no definitive studies on this have been done. Hartnoll (1982) has compared the growth pattern of four species of crustaceans. The final size and rate of increase were different for each, although they lived in similar environments, suggesting that the growth rate could be genetically regulated. For most species the growth rate slows as the animals get older (= larger). This is true for most crabs, which results from a combination of a smaller percent growth-increment at each molt with a longer molt interval. *Callinectes sapidus,* however, appears to be an exception to this rule. As the crabs get older the percent growth-increment actually increases slightly (Tagatz 1968, Hartnoll 1982), while the molt cycle increases. When the growth data of Tagatz (1968) are analyzed as percent increase per day per molt-cycle, it can be seen that, after a carapace width of 20 mm is obtained, the growth rate remains the same for all size groups (Figure 5). Thus, the growth rate of blue crabs appears to be fairly constant. This may account for the attainment of a large size in 2 years (Tagatz 1968).

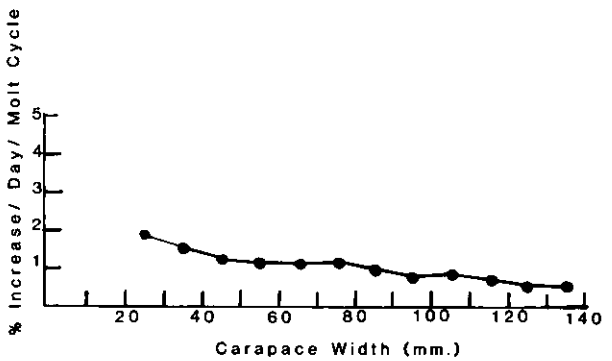

Figure 5. Growth rates (percent increase per day per molt cycle) for *Callinectes sapidus,* grouped by carapace width (data from Tagatz 1968).

Hormonal Control of Molting

The onset of premolt activities and the timing of the molt cycle are regulated by two endocrine factors. Molting hormone, ecdysone, is a steroid produced by the Y-organ, a gland located in the thorax (Gabe 1953; Echalier 1954, 1955; Chang and O'Connor 1977). Ecdysone is metabolized by peripheral tissues to 20-hydroxyecdysone (20-HE, crustecdysone, ecdysterone, β-ecdysone) which is a more active form of the molecule (Chang and O'Connor 1977) (Figure 6). This more active form, 20-HE, acts on the tissues to stimulate the premolt integumental activities (Vernet 1976, Kleinholz and Keller 1979).

Ecdysteroids are present in the hemolymph throughout the molt cycle, but levels are lower during late post- and intermolt (Figure 7) (Stevenson et al. 1979, Hopkins 1983). Several studies have demonstrated a small peak of ecdysteroids in stage B. The role of this peak is not understood at this time. The levels of 20-HE in the hemolymph begin to rise during early premolt and reach a peak during substage D_2, at the time of greatest synthesis of the cuticular chitin-protein lamellae (Soumoff and Skinner 1983). It is possible that the rate of increase in hormone level regulates the sequence of epidermal events. In studies where animals were treated with relatively high concentrations of 20-HE, the sequence of events were perturbed, a condition called hyperecdysonism. Here, the new cuticle underwent apolysis while still in stage D. In some instances the formation of the chitin-protein lamellae was also disturbed.

Following the hormone peak in substage D_2, blood levels dropped rapidly (Figure 7). These levels approached those measured in early pre- or intermolt stages by the time of ecdysis. This decline may continue briefly during the early phases of stage A. A decline in 20-HE is necessary for late premolt and for ecdysis to take place normally.

The second hormone regulating molting is the molt-inhibiting hormone (MIH). The molt-inhibiting hormone

has yet to be purified and chemically identified, but evidence gathered thus far suggests that it is a small peptide with a molecular weight of 2000 to 3000 daltons (Freeman and Bartell 1976, Freeman and Costlow 1979). It is produced in neurosecretory cells (X-organ) located in the eyestalks and is released from the sinus gland, a group of nerosecretory nerve endings (Passano 1960, Kleinholz and Keller 1979).

The evidence for MIH activity has come primarily from eyestalk-ablation experiments. Eyestalk removal, if done prior to early premolt (substage D_1), accelerates the molt cycle. If the sinus gland or extracts from the eyestalk are injected into an eyestalk-less animal, the molt cycle is slowed (Passano 1960, Freeman and Bartell 1975, 1976). Thus, MIH appears to regulate the rate of progress through the initial stages of premolt. After stage D_1, eyestalk ablation has no affect on the molt cycle (Drach 1944, Freeman and Bartell 1975). These data would suggest that MIH is present in the blood only during post- and intermolt, and declines during early premolt. The exact blood titre profile must await the future identification of MIH.

The physiological role of MIH is still not understood. Two possible mechanisms of action have been brought forward. The molt-inhibiting hormone may control molting by inhibiting the Y-organ from synthesizing and secreting ecdysone. Direct proof for this mechanism has been lacking until recently when Bruce and Chang (1984) demonstrated that eyestalk extracts could reduce ecdysone synthesis in crab Y-organs maintained *in vitro*. Jegla et al. (1984) showed that the Y-organ of crayfish could still be regulated by the eyestalks, even when moved to another part of the animal. These findings are interesting in light of other reports which show that crabs can go through five molt cycles after eyestalk removal (Freeman et al. 1983) and that 20-HE levels continue to undergo cyclical changes even in the absence of an eyestalk MIH factor (Chang and Bruce 1980; McCarthy and Skinner 1977b, 1979a).

An alternative hypothesis is that the MIH acts at the ecdysone target tissue (epidermis) in a manner which regulates the response of the tissue to ecdysone (Freeman and Bartell 1976, Freeman and Costlow 1979). In that case, the activity of the tissue would be regulated by the levels of both MIH and 20-HE.

The molt cycle can be accelerated by either eyestalk removal or 20-HE injection. Both methods have been employed in many studies on crustacean molting physiology (Passano 1960, Vernet 1976). The use of either technique in a commercial fishery or aquaculture has had limited testing with somewhat unsuccessful results (Smith 1973).

Limb Regeneration

The loss of walking legs or chelae can also affect the molt-cycle duration (Bliss 1960, Holland and Skinner 1976). Usually, however, many limbs must be removed to appreciably accelerate the molting rate (Skinner and Graham 1970).

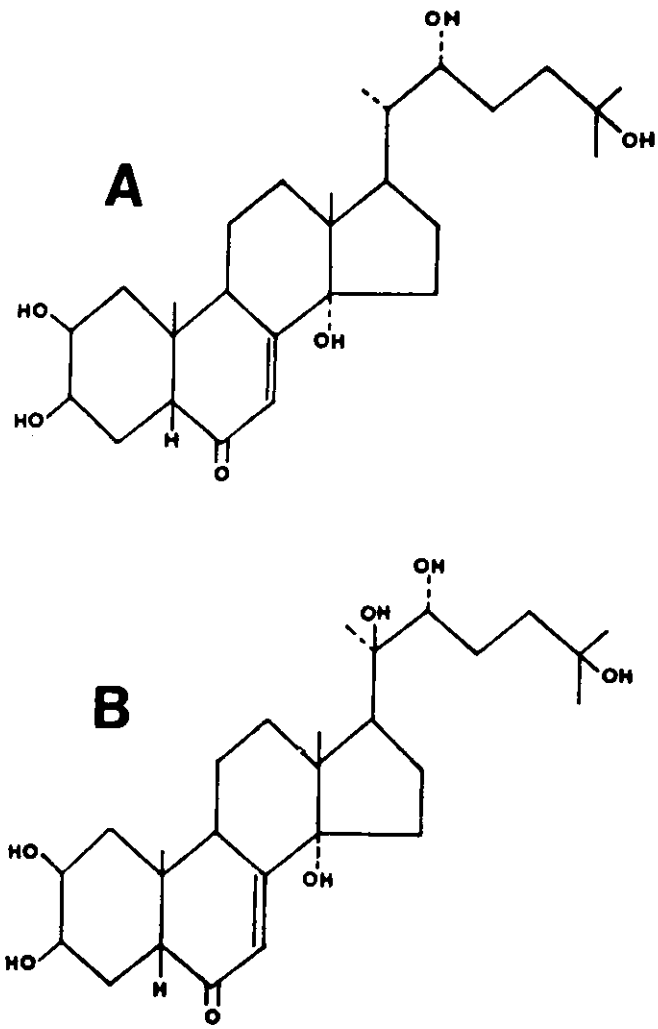

Figure 6. (A) The molting hormones ecdysone, and (B) 20-hydroxyecdysone. Ecdysone is secreted by the Y-organ and then metabolized by peripheral tissues to 20-hydroxyecdysone, the more active form of the hormone. Both hormones can stimulate molting.

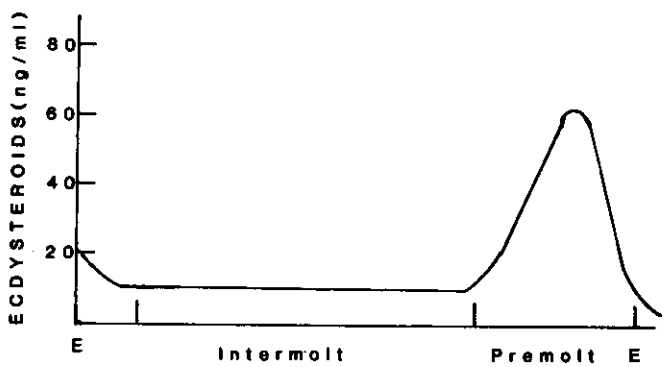

Figure 7. The ecdysteroid titre profile for one molt cycle. The levels rise during premolt and reach a peak at substage D_2 before declining during the remainder of the premolt period. The rate of the premolt rise is thought to stimulate and coordinate the synthetic activities of the epidermal cells.

Although the animal can regenerate the lost limbs, the risk of infection or blood loss as well as possible predation make limb removal an unacceptable means of regulating the molting rate. The regenerating limb, however, offers a means of determining progress through the molt cycle because the size of the limb bud increases throughout the premolt period (Bliss 1960). This technique has been employed with several species of crabs (Hopkins 1982, 1983; McCarthy and Skinner 1977 a, b). Recently, the use of limb-bud growth has been used to predict time of shedding in blue crabs (M. Poirrier and C. K. Bartell, pers. comm.).

IMPORTANCE TO THE SOFT SHELL CRAB FISHERY

The blue crab is one of the major constituents of the shellfish industry in the Gulf of Mexico, Chesapeake Bay and in the southeastern United States. However, the percentage of crabs that can be used for soft-shell production is low (~ 2%) (Otwell and Cato 1979), due in part to: (1) the inability to predict time to molt other than paddle-color signs, and (2) the inability to accelerate, or otherwise regulate, the molt cycle so that the crabs would not have to be held an unusually long time without feeding. Recent innovations in closed, recirculating holding facilities have made such shedding facilities an economically feasible means of soft-shell crab production on a small or large scale (Perry et al. 1979, Malone and Manthe 1984).

Future research endeavors are aimed at better defining the stages of the molt cycle and testing various means of hormonally stimulating the molting process. The improved staging methods can be of use in better predicting the time to molt for "green" (intermolt) crabs. These crabs comprise the majority of the catch and they are not currently kept for shedding. Thus, it may be possible to hold some of these crabs if they are in the later stages of intermolt or to class the crabs by molt-cycle stage if a closed system is modified such that feeding becomes a possibility.

Hormonally accelerating the molt cycle may be a means of stimulating intermolt crabs into premolt so that they could be kept in closed systems without feeding. This technology will involve defining an economically feasible dosage schedule so that the premolt period will occur normally, without hyperecdysonism, and yet not substantially increase the cost of handling or maintaining the crabs.

REFERENCES CITED

Adiyodi, K. G. and R. G. Adiyodi. 1970. Endocrine control of reproduction in decapod Crustacea. *Biol. Rev.* 45:121–165.

Arsenault, A. L., J. D. Castell and F. P. Ottensmeyer. 1984. The dynamics of exoskeletal-epidermal structure during molt in juvenile lobster by electron microscopy and electron spectroscopic imaging. *Tissue & Cell* 16:93–106.

Bliss, D. E. 1960. Autotomy and regeneration. Waterman, T. H. ed. *Physiology of Crustacea.* New York, N.Y.: Academic Press. 1:561–589.

Bruce, M. J. and E. S. Chang. 1984. Demonstration of a molt-inhibiting hormone from the sinus gland of the lobster, *Homarus americanus. Comp. Biochem. Physiol.* 79A:421–424.

Chang, E. S. and M. J. Bruce. 1980. Ecdysteroid titers of juvenile lobsters following molt induction. *J. Exp. Zool.* 214:157–160.

Chang, E. S. and J. D. O'Conner. 1977. Secretion of α-ecdysone by crab Y-organs *in vitro. Proc. Nat. Acad. Sci. USA* 74:615–618.

Dendinger, J. E. and A. Alterman. 1983. Mechanical properties in relation to chemical constituents of postmolt cuticle of the blue crab, *Callinectes sapidus. Comp. Biochem. Physiol.* 75A:421–424.

Dennel, R. 1960. Integument and exoskeleton. Waterman, T. H. ed. *Physiology of Crustacea.* New York, N.Y.: Academic Press. 1:449–472.

Drach, P. 1939. Mue et cycle d'intermue chez les crustacés décapodes. *Ann. Inst. Oceanogr.* 19:103–391.

_____ . 1944. Étude préliminaire sur le cycle d'intermue et son conditionnement hormonal chez *Leander serratus* (Pennant). *Bull. Biol. Fr. Belg.* 78:40–62.

_____ and C. Tchernigovtzeff. 1967. Sur la méthode de détermination des stades d'intermue et son application générale aux crustacés. *Vie Milieu Ser. A Biol. Mar.* 18:595–610.

Echalier, G. 1954. Recherches expérimentales sur le rôle de "l'organe Y" dans le mue de *Carcinus moenas* (L.) Crustacé Décapode. *C. R. Acad. Sci. (Paris).* 238:523–525.

_____ . 1955. Role de l'organe Y dans le déterminisme de la mue de *Carcinides (Carcinus) moenas* L. (Crustacés Décapodes); expériences d'implantation. *C. R. Acad. Sci. (Paris).* 240:1581–1583.

Freeman, J. A. and C. K. Bartell. 1975. Characterization of the molt cycle and its hormonal control in *Palaemonetes pugio* (Decapoda, Caridea). *Gen. Comp. Endocrinol.* 25:517–528.

_____ . 1976. Some effects of the molt-inhibiting hormone and 20-hydroxyecdysone upon molting in the grass shrimp, *Palaemonetes pugio. Gen. Comp. Endocrinol.* 28:131–142.

Freeman, J. A. and J. D. Costlow. 1979. Hormonal control of apolysis in barnacle mantle tissue epidermis, *in vitro. J. Exp. Zool.* 210:333–346.

_____ . 1980. The molt cycle and its hormonal control in *Rhithropanopeus harrisii* larvae. *Dev. Biol.* 74:479–485.

Freeman, J. A., T. L. West and J. D. Costlow. 1983. Postlarval growth in juvenile *Rhithropanopeus harrisii. Biol. Bull. (Woods Hole).* 165:409–415.

Gabe, M. 1953. Sur l'existence, chez quelques crustacés malacostracés, d'un organe comparable à la glande de la mue des insectes. *C. R. Acad. Sci. (Paris).* 237:1111–1113.

Hartnoll, R. 1982. Growth. Bliss, D. ed. *The Biology of Crustacea.* New York, N.Y.: Academic Press. 2:111–196.

Hegdahl, T., J. Silness and F. Gustavsen. 1977a. The structure and mineralization of the carapace of the crab (*Cancer pagurus* L.). I. The endocuticle. *Zool. Scr.* 6:89–99.

_____ . 1977b. The structure and mineralization of the carapace of the crab (*Cancer pagurus* L.). 2. The exocuticle. *Zool. Scr.* 6:101–105.

_____ . 1977c. The structure and mineralization of the carapace of the crab (*Cancer pagurus* L.). 3. The epicuticle. *Zool. Scr.* 6:216–220.

Holland, C. A. and D. M. Skinner. 1976. Interactions between molting and regeneration in a land crab. *Biol. Bull. (Woods Hole)* 150:222–240.

Hopkins, P. M. 1982. Growth and regeneration patterns in the fiddler crab, *Uca pugilator. Biol. Bull. (Woods Hole)* 163:301–319.

_____ . 1983. Patterns of serum ecdysteroids during induced and

uninduced proecdysis in the fiddler crab, *Uca pugilator*. *Gen. Comp. Endocrinol.* 52:350–356.

Jegla, T. C., D. Sedlmeier and R. Keller. 1984. Y-organ regulation in crustaceans. *Am. Zool.* 24:514 (abstract).

Kleinholz, L. H. and R. Keller. 1979. Endocrine regulation in Crustacea. Barrington, E. J. W. ed. *Hormones and Evolution.* New York, N.Y.: Academic Press. 1:160–213.

Koulish, A. 1973. Microtubules and muscle attachment in the integument of the Balanidae. *J. Morphol.* 140:1–14.

Malone, R. F. and D. P. Manthe. 1984. Interim design recommendations for closed-recirculating blue crab shedding systems. Louisiana State University. 1–13.

McCarthy, J. F. and D. M. Skinner. 1977a. Proecdysial changes in serum ecdysone titers, gastrolith formation and limb regeneration following molt induction by limb autotomy and/or eyestalk removal in the land crab, *Gecarcinus lateralis*. *Gen. Comp. Endocrinol.* 33:278–292.

_____ . 1977b. Interruption of proecdysis by autotomy of partially regenerated limbs in the land crab, *Gecarcinus lateralis*. *Dev. Biol.* 61:299–310.

Nakatani, I. and T. Otsu. 1981. Relations between the growth and the molt interval in the eyestalkless crayfish, *Procambarus clarki*. *Comp. Biochem. Physiol.* 68A:549–553.

Otwell, W. S. and J. C. Cato. 1982. Review of the soft-shell crab fishery in the United States. Perry, H. M. and Van Engel, W. A., eds. *Proc. Blue Crab Colloquium.* 16–19 October 1979. 30th Annual Fall Meeting, Biloxi, Mississippi. Available from: Gulf States Marine Fisheries Commission, Ocean Springs, MS. 7:129–136.

Passano, L. M. 1960. Molting and its control. Waterman, T. H. ed. *Physiology of Crustacea.* New York, N.Y.: Academic Press. 1:475–536.

Perry, H. M., J. T. Ogle and L. C. Nicholson. 1982. The fishery for soft crabs with emphasis on the development of a closed recirculating seawater system for shedding crabs. Perry, H. M. and Van Engel, W. A., eds. *Proc. Blue Crab Colloquium.* 16–19 October 1979. 30th Annual Fall Meeting, Biloxi, Mississippi. Available from: Gulf States Marine Fisheries Commission, Ocean Springs, MS. 7:137–152.

Price-Sheets, W. C. and J. E. Dendinger. 1983. Calcium deposition into the cuticle of the blue crab, *Callinectes sapidus*, related to external salinity. *Comp. Biochem. Physiol.* 74A:903–907.

Quakenbush, L. S. and W. F. Herrnkind. 1981. Regulation of molt and gonadal development in the spiny lobster, *Panulirus argus* (Crustacea; Palinuridae): effect of eyestalk ablation. *Comp. Biochem. Physiol.* 69A:523–527.

Roer, R. 1980. Mechanisms of resorption and deposition of calcium in the carapace of the crab *Carcinus maenas*. *J. Exp. Biol.* 88:205–218.

_____ and R. Dillaman. 1984. The structure and calcification of the crustacean cuticle. *Am. Zool.* 24:893–909.

Skinner, D. M. 1962. The structure and metabolism of a crustacean integumentary tissue during a molt cycle. *Biol. Bull. (Woods Hole)* 123:635–647.

_____ and D. E. Graham. 1970. Molting in land crabs: stimulation by limb removal. *Science* 169:383–385.

Smith, D. W. 1973. Effects of ecdysterone and inokosterone on ecdysis of the juvenile blue crab, *Callinectes sapidus*. Hattiesburg, MS: Univ. of Southern Mississippi. 33p. Thesis.

Soumoff, C. and D. M. Skinner. 1983. Ecdysteroid titers during the molt cycle of the blue crab resemble those of other Crustacea. *Biol. Bull. (Woods Hole)* 165:321–329.

Stevenson, J. R. 1968. Metecdysial molt staging and changes in the cuticle in the crayfish *Orconectes sanborni* (Faxon). *Crustaceana* 14:169–177.

_____ . 1972. Changing activities of the crustacean epidermis during the molting cycle. *Am. Zool.* 12:373–380.

_____ , P. W. Armstrong, E. S. Chang and J. D. O'Connor. 1979. Ecdysone titers during the molt cycle of the crayfish *Orconectes sanborni*. *Gen. Comp. Endocrinol.* 39:20–25.

Tagatz, M. E. 1968. Growth of the juvenile blue crabs, *Callinectes sapidus* Rathbun, in the St. Johns River, Florida. *U.S. Nat. Mar. Fish. Serv. Fish. Bull.* 67:281–288.

Tchernigovtzeff, C. 1965. Multiplication cellulaire et régéneration au cours du cycle d'intermue des Crustacés Decapodes. *Arch. Zool. Exp. Gen.* 106:377–497.

Travis, D. F. 1955. The molting cycle of the spiny lobster, *Panulirus argus* Latreille. II. Pre-ecdysial histological and histochemical changes in the hepatopancreas and integumental tissues. *Biol. Bull. (Woods Hole)* 108:88–112.

_____ . 1957. The molting cycle of the spiny lobster, *Panulirus argus* Latreille. IV. Post-ecdysial histological and histochemical changes in the hepatopancreas and integumental tissues. *Biol. Bull. (Woods Hole)* 113:451–479.

Vernet, G. 1976. Donneés actuelles sur le determinisme de la mue chez les crustaces. *Annee Biol.* 15:155–188.

Vigh, D. A. and J. E. Dendinger. 1982. Temporal relationships of postmolt deposition of calcium, magnesium, chitin and protein in the cuticle of the Atlantic blue crab, *Callinectes sapidus* Rathbun. *Comp. Biochem. Physiol.* 72A:365–369.

Wittig, K. and J. R. Stevenson. 1975. DNA synthesis in the crayfish epidermis and its modification by ecdysterone. *J. Comp. Physiol.* 99:279–286.

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POST–MOULT CALCIFICATION IN THE BLUE CRAB

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ABSTRACT During the 8 days following moulting in the blue crab *Callinectes sapidus* Rathbun, calcification proceeds at an extremely rapid rate. The uptake of Ca^{2+} ions from the external seawater is accompanied by equally rapid uptake of bicarbonate ions and excretion of H^+ ions. External bicarbonate is the source of most of the newly formed carbonate because metabolism generates CO_2 at a much lower rate, and the animal shows a net CO_2 uptake for several days. The acidification of the external medium which accompanies calcification requires a large and/or well-buffered holding system. Interference with the process, such as with reduced external calcium, causes serious disturbance in acid-base and other regulatory systems.

INTRODUCTION

A newly moulted crab has an urgent need to produce a new rigid carapace as quickly as possible. Besides its increased vulnerability to predation, it is not capable of full muscular power for many activities without a strong exoskeleton. Although the new carapace tissues are almost fully formed beneath the old carapace during the pre-moult period, the mineral portions which provide the strength and rigidity must be laid down after the new carapace is "pumped up" to its new size.

Contrary to the impression given in some reviews (cf. Passano 1960), marine crabs resorb and conserve little or none of the mineral material of the shed carapace (Cameron and Wood 1985). New mineral material must be obtained from the external environment during the period following moult. Calcium carbonate is formed according to the reaction:

$$Ca^{2+} + CO_2 + H_2O \Rightarrow CaCO_3 + 2H^+$$

so the inward movement of calcium must be accompanied by corresponding movements of CO_2 and H^+ ions. In the past year or so, we have carried out a variety of studies of the mineral micro-environment in the blue crab's carapace, and have performed various experimental work on the process of replacement following moulting.

METHODS AND MATERIALS

Pre-moult crabs (identified by signs as described by Perry et al. 1979) were collected from March through November 1984, in Redfish Bay, TX, using shaded "peeler pots." The crabs were transported to the laboratory and maintained in individual aquaria until they moulted. Food was offered *ad libitum*, but was usually declined for the day or two preceding the moult.

The size and composition of the shell were measured in a series of intermoult and post-moult crabs. To assess the total shell weight, animals were weighed wet, then all parts of the shell were carefully dissected away from the soft tissues. The shell was kept humid to prevent drying and the total weight of the parts measured. These were then dried and reweighed to give the shell dry weight and shell water content, by difference. The dried material was then extracted in 2 M HCl for several days, and the residue redried and weighed. The difference in weight before and after acid extraction was termed the acid-labile portion. The acid extracts were saved for various chemical analyses which were performed using conventional laboratory methods.

For total calcium measurements, whole carcasses were dried, minced, and extracted in a known volume of 2 M HCl for about a week with frequent agitation. The extract was filtered, and aliquots of it analyzed for calcium concentration.

For various flux and metabolic measurements, the crabs were placed in a darkened lucite chamber incorporated into a recirculating, small-volume system with temperature control and aeration. Various manipulations, including changes in the external water and blood sampling, were possible with minimal disturbance to the animal. The measurements included oxygen consumption, CO_2 production, net apparent H^+ excretion, calcium uptake, ammonia excretion, titratable acidity, and ionic analyses of blood and water. The methods for each of these have been described in detail elsewhere (Cameron and Kormanik 1982, Cameron and Wood 1985, Wood and Cameron 1985).

RESULTS

Shell Compartment

The carapace accounts for more than one quarter of the total live weight of the blue crab (Figure 1), and more than half of the dry matter. Of the dry carapace material, an average of 73% was acid-labile, and the composition of this (principally mineral salt) portion is given in Table 1. Various analyses performed accounted for 85% of the acid-labile portion and the rest was probably acid-soluble organic

materials, such as proteins, and water of hydration released from the mineral matrix upon acidification.

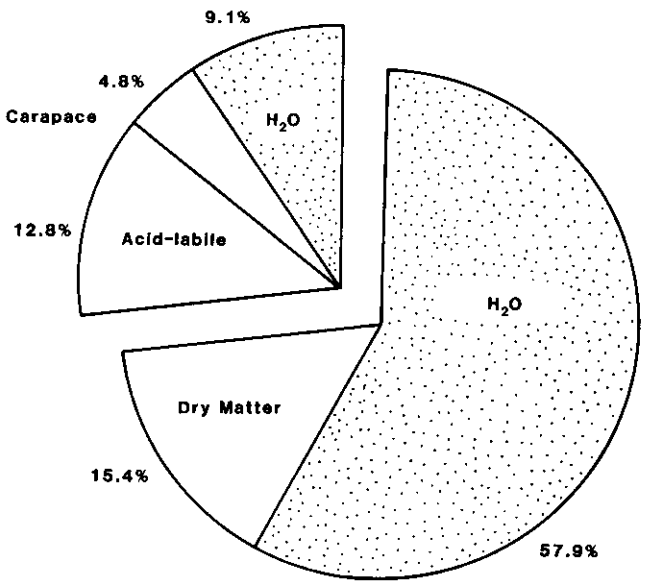

Figure 1. Distribution of wet, dry, and acid-labile weight of the carapace as fractions of the total live (wet) weight of the blue crab on a 1-kg basis. The stippled portion represents water compartments and the unshaded portions, the various dry matter components.

TABLE 1.

Composition of the mineral (acid-labile) portion of the carapace from intermoult blue crabs. These data were obtained from 22 crabs and a total of 114 samples. Means ± standard error (se) are given per 100-g of acid weight loss of the dried carapace material. The carbonate concentration was calculated as the titratable base minus two-thirds of the phosphate concentration (from Cameron and Wood 1985).

Species	g/100 g (%)	Equivalent
Ca^{2+}	29.1 ±0.5	1.45 ± 0.03
Mg^{2+}	1.7 ±0.05	0.14 ± 0.004
Sr^{2+}	0.41 ±0.03	0.01 ± 0.001
PO_4^{3-}	3.4 ±0.1	0.11 ± 0.004
$CO_3^{=}$	48.9	1.63
Titratable Base		1.70 ± 0.06
Na^{+}	1.3 ±0.1	0.06 ± 0.004
K^{+}	0.3 ±0.04	0.01 ± 0.001
Total	85.1	

The shell water, about 14% of the total body water, has been shown to remain about 0.5 pH unit more alkaline than blood and nearly 1 pH unit above most other tissues (Wood and Cameron 1985), undoubtedly to maintain an appropriate environment for the principle mineral salt, calcium carbonate. This contrasts with vertebrates, whose skeletons are primarily calcium phosphate, rather than carbonate; phosphate salts remain insoluble at normal body pH values.

Whole Body Calcium Pool

The total body calcium content is roughly 1 mole/kg (Figure 2), and declines to only a few percent of this value immediately after the moult. During the next 7 days, calcium content increased to about one-half the intermoult value, and this increase in calcium was accompanied by a rapid apparent net H^+ excretion (Figure 3). Measurements of the net inward flux of calcium corresponded to the observed increase in whole body calcium, with peak rates of uptake of around 10 mEquiv/kg-hr.

Metabolism and the Source of Carbonate

Metabolic measurements (Figure 4) show that CO_2 is actually being absorbed by the crab for the first 5 days, rather than excreted, indicating that HCO_3^- must be taken up from the seawater to act as a CO_2 source for $CaCO_3$ being formed in the carapace. The oxygen consumption rates were about twice the resting, intermoult values; assuming that the true metabolic RQ was 0.9, there was a large net CO_2 deficit which correlated closely with the observed rates of calcification and must correspond to the rate of bicarbonate uptake from the external seawater.

DISCUSSION

Past studies of post-moult mineralization have focussed mainly on the calcium uptake and deposition in the shell (Roer 1980, Vigh and Dendinger 1982), but it has not been appreciated that such a rapid influx of calcium must be accompanied by other ion movements that ensure both electrical and acid-base balance in the crab. A general scheme for accounting for the various ion movements is shown in Figure 5. Both Ca^{2+} and HCO_3^- are transported from the external seawater into the blood and finally to the carapace fluid space. The HCO_3^- ion is, of course, always in equilibrium with $CO_3^=$ and H^+ ions and, as $CaCO_3$ is formed, equimolar quantities of H^+ ion are also formed. These must be transported back through the blood and finally into the external seawater to maintain acid-base balance.

If metabolically produced CO_2 acts as a significant source for carbonate formation, then two H^+ ions are generated per $CaCO_3$ formed, with no direct uptake of bicarbonate. Our data actually favor the direct uptake of bicarbonate for two reaosns. First, the rate of calcification for the first day or two is several times higher than the expected metabolic production of CO_2; and, second, the blood values for CO_2, HCO_3^-, and pH remain normal. This latter means that the partial pressure gradient will favor continued diffusion of gaseous CO_2 out of the crab, making

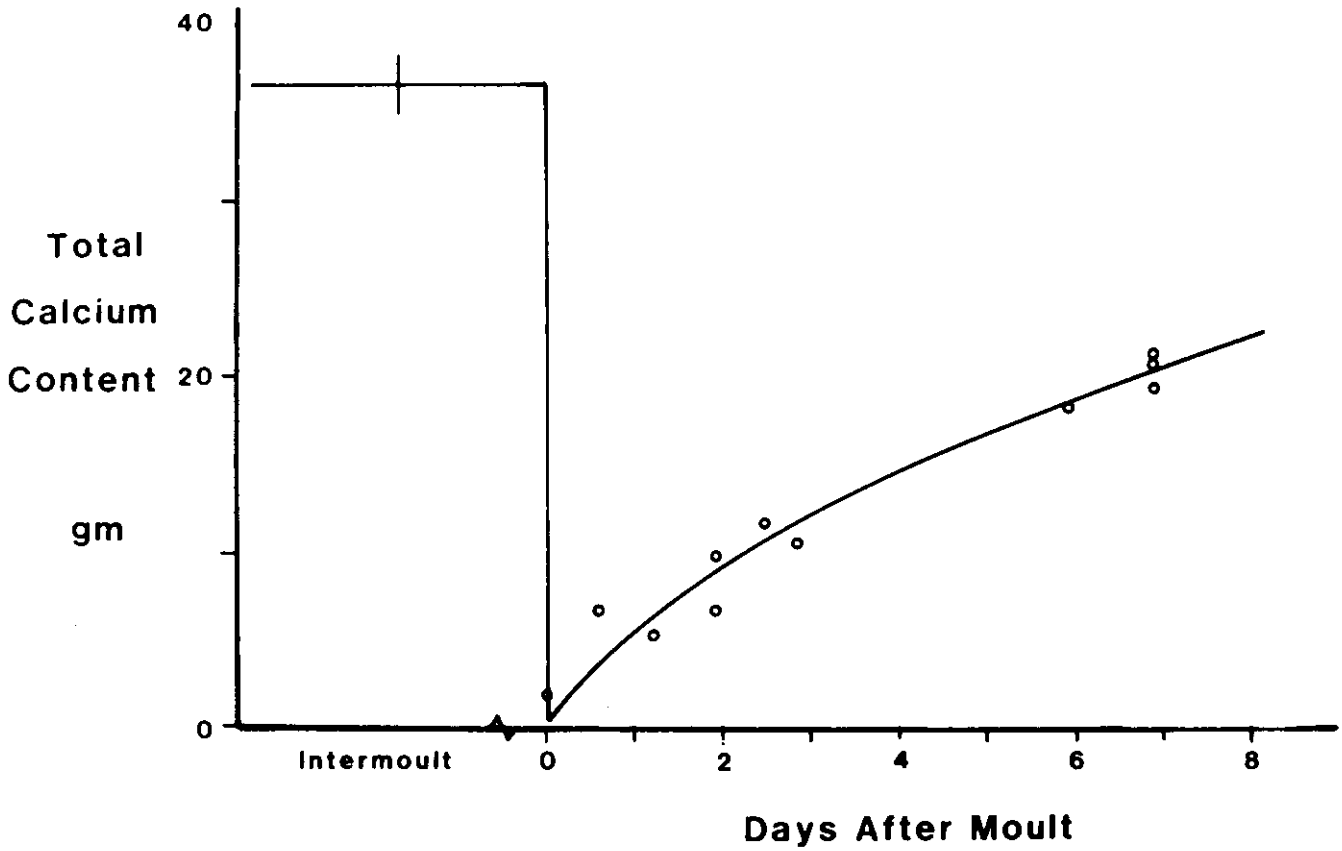

Figure 2. The total body calcium content of the intermoult blue crab (left portion) and of crabs at various times post-moult (open circles).

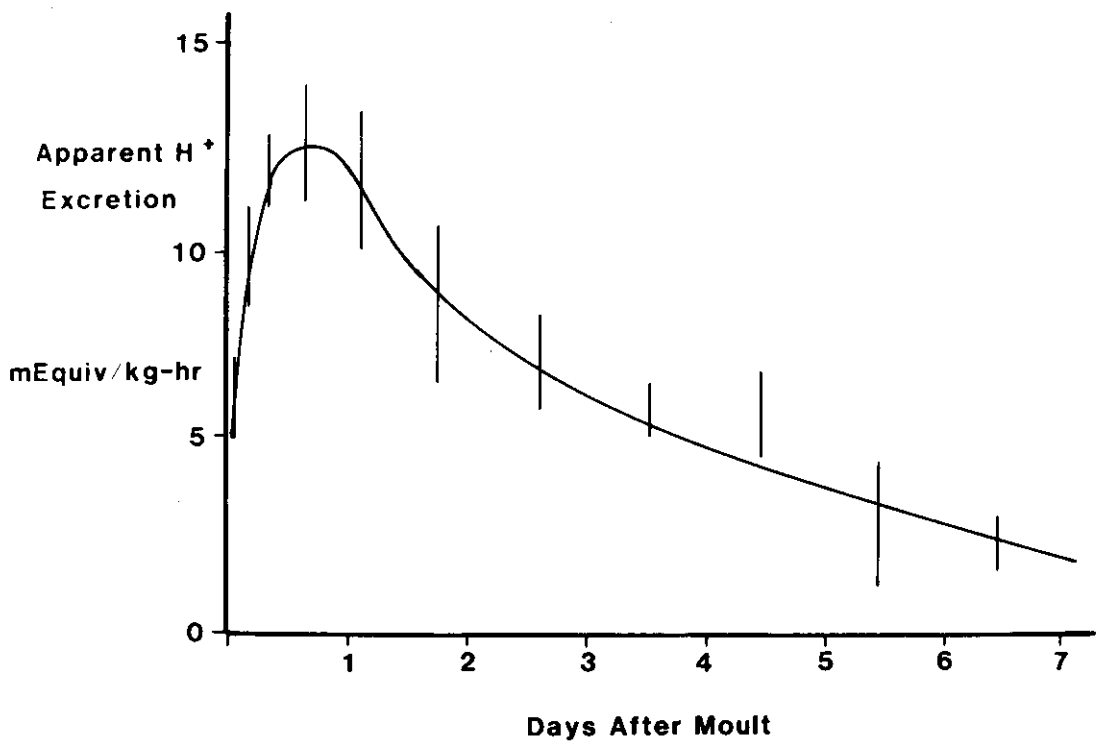

Figure 3. The apparent net H^+ excretion rates of blue crabs after moulting. This measurement takes all acid-base related ion movements into account, including H^+ excretion, ammonium ion excretion, and bicarbonate uptake. A positive value represents net H^+ excretion.

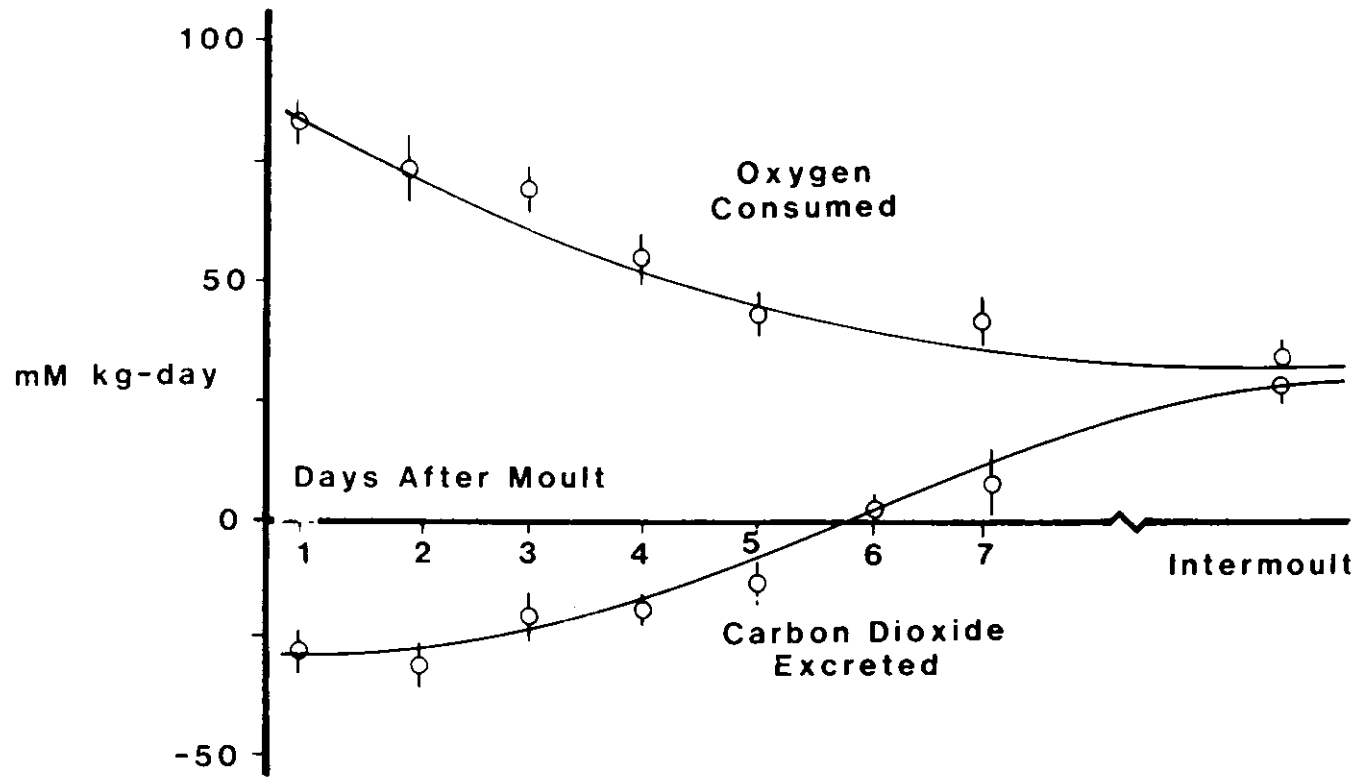

Figure 4. Rates of oxygen consumption and CO_2 excretion (or uptake) during the days following moulting. These data are for 6 post-moult and 3 intermoult crabs.

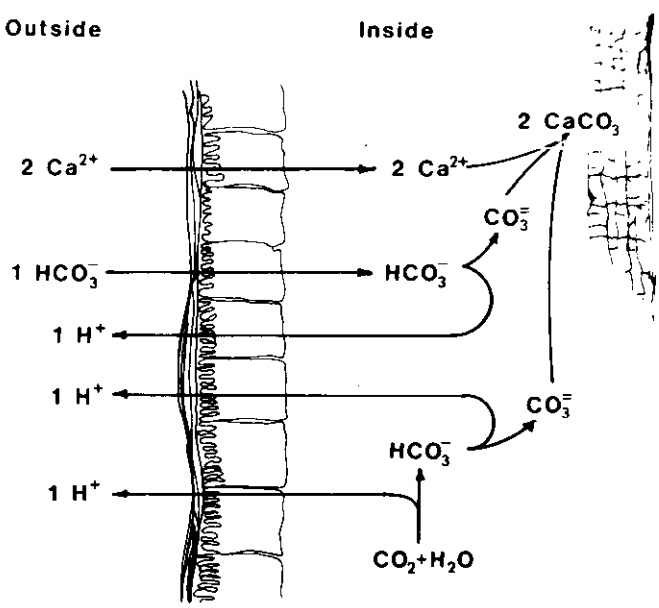

Figure 5. A schematic diagram of the ion movements between the external medium and the crab during the post-moult calcification period.

the requirement for direct HCO_3^- uptake even larger. A final possibility is that as H^+ ions are excreted across the gills, the seawater equilibrium is shifted to produce higher CO_2 partial pressures, which would then cause diffusion back into the crab. This alternative is unlikely because the water does not stay in the gills long (< 1 second; Cameron 1979), and the reaction with H^+ to produce CO_2 has a half-time of 20 to 30 seconds at usual seawater temperatures. Thus, significant amounts of CO_2 would not be formed while the water was still in contact with the gills.

Practical Consequences

The extremely high rates of ion transport across the gills during the post-moult period pose some interesting theoretical questions and have some important practical consequences. It is of great theoretical interest to know the mechanisms for the various ion movements and it would be nice to know something about the hormonal control, particularly of the calcium flux. Although a large number of polypeptide hormones have been described from the neurosecretory organs in the eye stalk, for example, none has any known effect on calcium metabolism.

There are also the practical consequences of the extremely high acidification rate. An average size crab will remove one-third to one-half of the bicarbonate from 10 gallons of seawater overnight and, at this point, the process becomes self-limiting. The crab will die if allowed to acidify to a very great extent. Similarly, attempts to remove calcium from the external environment also leads to rapid death because various physiological systems are unable to function when the blood calcium concentration

drops. The post-moult crab must be kept in either a large volume of water or in a system that is well buffered and where the calcium concentration is maintained at about 75% of the normal seawater value or above.

REFERENCES CITED

Cameron, J. N. 1979. Excretion of CO_2 in water-breathing animals: A short review. *Mar. Biol. Lett.* 1:3–13.

_____ & G. A. Kormanik. 1982. The acid-base responses of gills and kidneys to infused acid and base loads in the Channel catfish, *Ictalurus punctatus*. *J. Exp. Biol.* 99:143–160.

Cameron, J. N. & C. M. Wood. 1985. Apparent H^+ excretion and CO_2 dynamics accompany carapace mineralization in the blue crab *(Callinectes sapidus)* following moulting. *J. Exp. Biol.* 114:181–196.

Passano, L. M. 1960. Molting and its control. T. H. Waterman, ed. *The Physiology of Crustacea*. New York, NY: Academic Press. Vol. 1, 743–536.

Perry, H. M., J. T. Ogle & L. C. Nicholson. 1979. The fishery for soft crabs with emphasis on the development of a closed recirculating seawater system for shedding crabs. Sea Grant Publ. No. LSU–WA 82–001. 16 p.

Roer, R. D. 1980. Mechanisms of resorption and deposition of calcium in the carapace of the crab *Carcinus maenas*. *J. Exp. Biol.* 88:205–218.

Vigh, D. A. & J. E. Dendinger. 1982. Temporal relationships of postmolt deposition of calcium, magnesium, chitin and protein in the cuticle of the Atlantic Blue Crab, *Callinectes sapidus* Rathbun. *Comp. Biochem. Physiol.* 72A:365–369.

Wood, C. M. & Cameron, J. N. 1985. Temperature and the physiology of intracellular and extracellular acid-base regulation in the blue crab *Callinectes sapidus*. *J. Exp. Biol.* 114:151–179.

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985, 37–39.

THE FISHERY FOR SOFT CRABS: RULES AND REGULATIONS, MANAGEMENT IMPLICATIONS

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In recent years most states have seen an expansion in the soft-crab fisheries, especially those in the South Atlantic and Gulf of Mexico states. This is due primarily to the potential economic returns, the demand for soft crabs, and the promotional and extension efforts in most states, to name a few.

Most soft crabs are produced by holding peeler crabs in a shedding system. Therefore, the primary fishery is for peeler crabs to supply the shedding facility, although some wild harvesting of soft crabs does take place. Peelers are harvested by a wide variety of fishing methods. A number of these methods were developed in the Chesapeake Bay area where a long history of soft-crab production has existed and where a major fishery continues to exist.

The majority of peeler crabs are caught incidental to the catch of hard crabs with traditional pots, and this incidental catch can result in additional income for traditional crabbers. In addition, peeler potting and habitat pots are used. Peeler pots are those pots which are baited with a "jimmy" or male crab to attract immature females. This is used in certain areas containing large numbers of females. Habitat pots are traditional pots covered with plastic or other material to provide secure hiding places for shedding. Although they are not widely used, they have been shown to produce peelers in tests conducted in South Carolina.

Scrapes are used to harvest peelers in the Chesapeake Bay area, especially in Maryland. Scrapes are lightweight dredges with no teeth and a bag towed by power in grassbeds. Grassbeds tend to have relatively high concentrations of peeler crabs seeking protection during shedding. As a result, scrapes are an effective method for harvesting peelers.

Similarly, crabbers in North Carolina use peeler trawls to harvest peelers. These are generally small otter trawls towed for short durations in areas with high concentrations of peelers. In addition, peelers are occasionaly kept incidental to shrimping and hard-crab trawling. However, peelers taken in this manner generally are of lower quality and have higher mortality rates unless special care is taken.

A traditional gear used in the Chesapeake Bay area is the peeler pound or bank pound, the use of which is rapidly expanding into other areas. Generally, these are shallow-water pound nets made of wire or netting. They take advantage of and trap crabs while they are moving in shallow water.

In addition to those soft-shell crab gear types described above, peelers are also taken with dip nets, trotlines, bushlines, etc. In general, fishermen are very ingenious when it comes to catching something as potentially valuable as a soft or peeler crab.

There are relatively few rules and/or regulations that apply specifically to the soft- and peeler-crab fisheries (Table 1). Most states require a license either generically to fish commercially or specifically to crab. The states of South Carolina, Georgia and Florida require a soft-shell dealer or shedder permit. These permits are used primarily to identify soft and peeler crabbers so they may retain undersized hard crabs.

Minimum-size limits for soft and peeler crabs vary considerably from state to state. Virginia, North Carolina, South Carolina, Florida, Mississippi and Texas have no minimum size requirements for either soft or peeler crabs (Table 1). Although Alabama has a 4-inch-minimum size limit for crabs, there is no indication that the limit also applies to soft and peeler crabs. For soft crabs, Maryland has a 3.5-inch-minimum size limit, while Louisiana has a 4.5-inch-size limit. A 3-inch-minimum size for peeler crabs is required by Maryland and Georgia regulations. Minimum sizes are measured from tip-of-spike to tip-of-spike.

Most states have some regulations which include such items as area, seasonal and design restrictions; limits on particular gears; prohibition of certain gears; and permitting/registering requirements. All states allow pots to be used, but most have some restrictions, i.e., buoying and marking requirements, areas they may be used, and limits on the number of pots used. Peeler pounds are allowed in some states although registration and/or permits are required in addition to other restrictions. Scrapes are allowed in the Chesapeake Bay states with certain restrictions, while South Carolina allows them only with a special permit. Specific trawling for peelers is allowed in North Carolina with certain restrictions; other states allow soft and peeler crabs to be kept incidental to legal-shrimp trawling; and Maryland and Virginia do not allow any trawling. Maryland, Virginia and South Carolina have a legal definition for soft crabs, peeler crabs and/or other crabs; Virginia also defines a peeler pot.

Recently, a number of management issues have been raised in North Carolina. These issues may also be pertinent

TABLE 1.

Regulations pertaining to peeler and soft-shell blue crabs from Maryland to Texas

State	License Required to Fish	Soft-Shell License or Permit	Minimum Size (inches)		Gear Type				Definition			Comments
			Soft-Shell	Peeler	Pot	Pound	Scrape	Trawl	Soft-Shell	Peeler	Other	
Maryland	Yes	No	3.5	3.0	3*	3	3	1*	No	Yes	Yes	
Virginia	Yes	No	None	None	3	3	3	1	No	Yes	No	Define peeler pot; sanctuaries closed to all gears; peeler pounds licensed
North Carolina	Yes	No	None	None	3	2*	1	3	No	No	No	Peeler pound registration required; sanctuaries closed to all gears by proclamation
South Carolina	Yes	Yes	None	None	3	Spec. Permit	Spec. Permit	1	Yes	Yes	No	Permit or ID card required to keep undersized peelers
Georgia	Yes	Yes	None	3.0	2	1	1	1	No	No	No	Peelers only sold to licensed soft-shell dealers
Florida	Yes	Yes	None	None	3	Spec. Permit	1	1	No	No	No	Extensive buoying & marking requirements for pots; quarterly data required for peeler pounds
Alabama	Shrimp Trawl	No	None	None	2	1	1	3	No	No	No	Crabs may be kept from legal shrimp trawling; no minimum size for personal consumption
Mississippi	Yes	No	None	None	2	1	1	2	No	No	No	
Louisiana	Yes	No	4.5	None	2	1	1	1	No	No	No	Shrimpers may keep incidental crabs
Texas	Yes	No	None	None	3	1	1	3	No	No	No	Shrimpers may keep incidental crabs

*1: not allowed; 2, allowed; 3, restrictions

to most states, although there may be issues unique to each state and fishery. This paper is not designed to be a complete discussion of all of the issues. There may also be differences in opinions and judgments concerning issues because of differences in management philosophies and in the types of fisheries involved.

It is important in fisheries management to develop a management philosophy or objective for the individual fishery or species being managed. In North Carolina, the management philosophy towards soft- and peeler-crab harvest is to maximize the harvest without unduly damaging other important resources while minimizing conflicts with other fisheries. This approach takes into account the relatively high-economic value of soft crabs, but also realizes the value of the other resources, i.e., shrimp, oysters and finfish. Because no parent/progeny relationship has been established for crabs, we view this fishery as any other annual crop: maximize harvest. Because of the multitude of fisheries in North Carolina, one fishery cannot occupy an area to the exclusion of another, therefore, management philosophies may and do change for a variety of reasons.

Obviously, one of the most important concerns in resource management is to protect the habitat which sustains that resource. Effort must be made to identify and minimize those manmade-environmental influences which affect the resource. Protection of grassbeds, nurseries and

shallow estuaries, etc., are essential to maintaining soft and peeler crab production. In addition, maintaining conditions of good water quality is necessary because most shedding is done with flow-through systems.

Another area of concern to resource management is the adequacy of landing statistics. Because of the "back-yard" shedding occurring and the exchanging and handling of peelers, there are questions about the ability to collect adequate statistics. No doubt port agents have difficult times tracking down landings. Most states have pointed to this as a major problem. Another area of concern relates to the validity of lumping peelers and soft crabs into one category. Does this adequately reflect the true value? Are the landings primarily peelers or soft crabs? Do these landing data adequately reflect the trends in soft-crab production? Because of the value of the fishery and its growing importance, it may be necessary to place additional emphasis on collecting soft-crab statistics. Consideration should also be given to how these statistics are to be reported, i.e., soft and peeler combined or separated, while maintaining consistency between states.

Judging from the regulations from each of the states, size limits for soft and peeler crabs appear to be a major issue. Should there be a size limit? Because the catch of peelers and soft crabs is such a minor percentage of landings for North Carolina, as well as in most states, size limits are biologically unnecessary, especially in light of the economic value of the individual crab. If size limits are based on market demands, then fickle-market conditions might best regulate the size. Again, the management philosophy of North Carolina is to maximize harvest and economic value.

Along the same line as size limits is the issue of overharvesting undersized females. With the increase in peeler crab harvest in recent years, fishermen are questioning whether we may be overharvesting crabs and especially immature females. If hormonal inducement of shedding gains widespread use, potentially larger numbers of immature females may be taken. Because no parent/progeny relationship has been established and peelers currently occupy a relatively low percentage of the blue crab harvest, overharvesting does not appear to be a biological reality at this time. However, these potential social conflicts will probably continue to occur.

An issue dealt with in North Carolina was the mandatory requirement of cull rings or escape ports in hard-crab pots. Cull rings gained wide popularity throughout Pamlico Sound, and potters requested that they be made mandatory. However, a study was conducted of cull rings to determine their effectiveness to cull and to evaluate peeler loss from hard-crab pots. In general, the study indicated that cull rings could not replace the current 5-inch-minimum size limit with a 10% tolerance for hard crabs caught in pot. Overall we found a 40% loss in peelers in pots equipped with cull rings. Because most of the peeler supply comes from hard-crab pots, we felt this would have an adverse impact on the growing soft-crab industry. If you are considering mandatory cull-ring regulations, peeler loss should be evaluated.

Another issue in North Carolina was the potential impact of some gear-types on other resources. Potentially towed gears, such as peeler trawls and scrapes, could damage grassbeds, cause mortalities of shrimp and valuable finfish, and damage oyster beds. We attempted to address these potential impacts by specifically regulating where these gears may be used. We now have proclamation authority to open and close areas to peeler trawling on a 48-hour notice. Crab dredging is illegal for most of North Carolina and scrapes are prohibited. Potentially intensive use of scrapes could damage the grassbeds that the scallop and pink shrimp fisheries depend on. As the soft and peeler crab fisheries continue to grow, scrutiny will continue to be given to allowing peeler harvesting but minimizing the damage to other important resources. A study is being conducted to determine distribution and seasonal abundance in various habitats throughout the Pamlico Sound area.

Widely diversified types of fisheries exist in North Carolina. Often these different fisheries occupy the same area. A shrimp fishery, haul seine fishery, or peeler trawl fishery cannot exist in an area that is intensively potted or pound netted either for fish or peeler crabs. Therefore, resource managers often regulate where a fishery may take place. These are very difficult issues, but a particular gear cannot operate to the exclusion of another. No doubt this would be the result in some areas of North Carolina if we did not regulate. We often make resource-allocation decisions to provide opportunity to fish by various fisheries. Fortunately, we have not had many issues occur relative to the allocation of the soft and peeler crab resource, but if expansion in those fisheries continues they are no doubt on the horizon.

Some managers in other states may be involved in these same issues or possibly others. Obviously, some of these issues are generic from state to state. However, many of the issues can only be addressed relative to the fisheries, resources, philosophies, and legal authorities unique to a given area. Specific management needs should be tailored to the situation if proper management is to be effective.

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985, 41–47.

CHEMICAL ADDITION FOR ACCELERATED NITRIFICATION OF BIOLOGICAL FILTERS IN CLOSED BLUE CRAB SHEDDING SYSTEMS

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INTRODUCTION

Louisiana remains the largest supplier of soft crabs to the Gulf states, but reported landings have fluctuated widely. The production drop in recent years has been attributed to a number of factors, including a decline in coastal water quality, loss of natural habitat, and disease (Jaworski 1971, Perry et al. 1982). The regrowth and expansion of the fishery is now being stimulated by the adoption of closed, recirculating-seawater systems to hold and shed peeler crabs.

This paper examines filter acclimation responses of several crab-shedding systems impacted by different media size, commercial additives containing nitrifying bacteria, and identifies chemical-addition methods that could be used to accelerate filter acclimation in a commercial setting.

BACKGROUND

The potential value of using closed systems for shedding crabs has now been demonstrated by a number of commercial operators (Perry et al. 1982, Manthe et al. 1983). The success of these systems has often been marginal due to the lack of established design criteria and management guidelines. Table 1 presents recently developed design criteria. From these criteria, one can design a crab-shedding system that is safe and commercially viable. The operation of a successful, closed, recirculating aquaculture system depends on the maintenance of acceptable water quality. The ability of biological filters in the closed systems to convert ammonia (NH_3), the principal nitrogenous excretory metabolite of Crustacea (Hartenstein 1970), to the relatively nontoxic nitrate (NO_3) by bacterial nitrification is summarized by Wheaton (1977) and Spotte (1979). In crab-shedding systems, nitrite has been identified as the most toxic form of nitrogen to crabs. Increases in the nitrite (NO_2) concentrations resulting from the conversion of crab wastes has been identified as the limiting water-quality parameter in these systems where the biological filters are not acclimated to high loadings (Manthe et al. 1984).

Figure 1 presents guidelines for nitrite concentrations derived from successful commercial operation. The safe zone designates the area of optimum operational ability. The systems are in balance with the crab-produced waste and baseline water-quality conditions exist. The marginal zone indicates the concentration range associated with moderate molting mortality with the crabs dying while backing out of their shell. The chronic mortality zone reflects substantial molting loss, while the acute mortality zone defines the range of nitrite that will kill even intermolt crabs.

TABLE 1.

Interim design recommendations on a per crab basis.

System Component	Design Parameter	Design Criteria
Crab tank	Volume	0.4 gal/crab
	Flow rate	0.015 gal/min/crab
	Surface area	0.16 sq ft/crab (desirable)
Biological filter	Media volume	0.03 cu ft/crab
	Water volume	0.15 gal/crab
	Flow rate	0.02 gal/min/crab
	Surface area	0.05 sq ft/crab (desirable)
Sump	System volume	2.0 gal/crab
	Sump volume	1.45 gal/crab

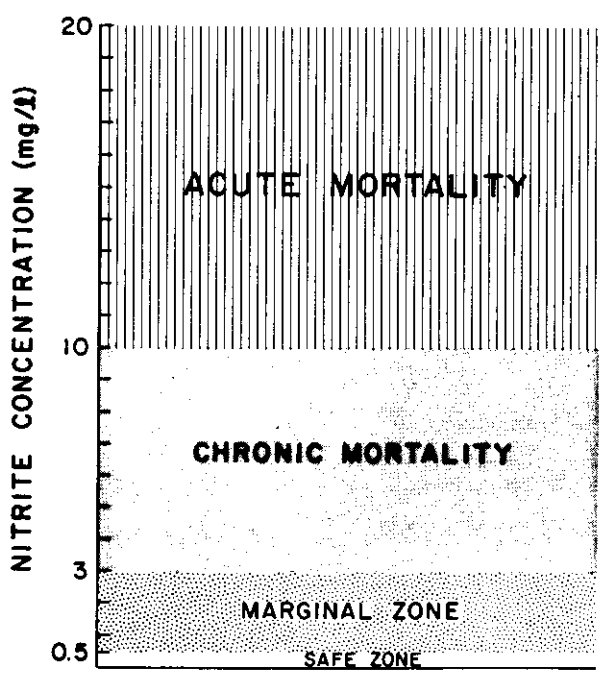

Figure 1. Observed toxic nitrite concentrations in commercial crab shedding operations.

Due to the seasonal use of the crab-shedding systems (normally May through October), the biological filters must be acclimated at the start of every soft-shell crab season. Traditionally, the acclimation of submerged biological filters for aquaculture systems takes from 30 to over 100 days (Hirayama 1974, Mevel and Chamroux 1981, Manthe et al. 1984). The startup of the filters used in shedding systems usually consists of introducing intermolt crabs or estuarine fish to the systems to buildup the bacteria in the filters to a level that will accept the loading of peeler crabs for the production of soft-shells. Unfortunately, this method of filter preparation often corresponds with the spring run of premolt crabs. The spring run causes the largest influx of peeler crabs during the season and, consequently, is the most profitable time of the year for the soft-shell producer. If the systems are not properly acclimated to accept the loading placed on them by the large amount of crabs, system failure and high mortality of valuable peeler crabs can result from the declining water quality. Thus, methods to decrease biological filter acclimation time during this crucial period should increase productivity and revenues to the operator and provide safe operation of shedding systems during periods of heavy crab loading.

MATERIALS AND METHODS

Six experimental systems were constructed on a 3% scale of successful commercial systems described and monitored by Manthe et al. (1983). Experimental tanks were made of plexiglass and all plumbing was of polyvinylcloride (PVC) and similar to previous experimental work (Manthe et al. 1984). Dimensions and a schematic of the experimental systems are presented in Table 2 and Figure 2, respectively. Total system volume was 225 ℓ and maximum loading capacity was determined to be 20 crabs.

TABLE 2.

Dimensions of experimental systems.

Description	Length (ft)	Width (ft)	Depth (ft)	Water Depth (ft)	Area (ft^2)	Volume (ft^3)
Crab tank	3.0	2.0	1.0	0.838	6.0	2.625
Biological filter tank	1.167	1.0	1.5	1.0	1.167	1.167
Mechanical filtration bed*	1.167	0.5	0.5	--	0.584	0.292
Limestone filter bed*	1.167	1.0	0.5	--	1.167	0.584
Sump	3.0	2.0	1.0	0.7083	6.0	4.25

*Subcompartment of biological filter tank
Note: 1 ft = 0.3048 m

Water level in the upper tank was controlled by a 5-in. (12.7 cm) standpipe constructed of 1.5-in. (3.8 cm) PVC

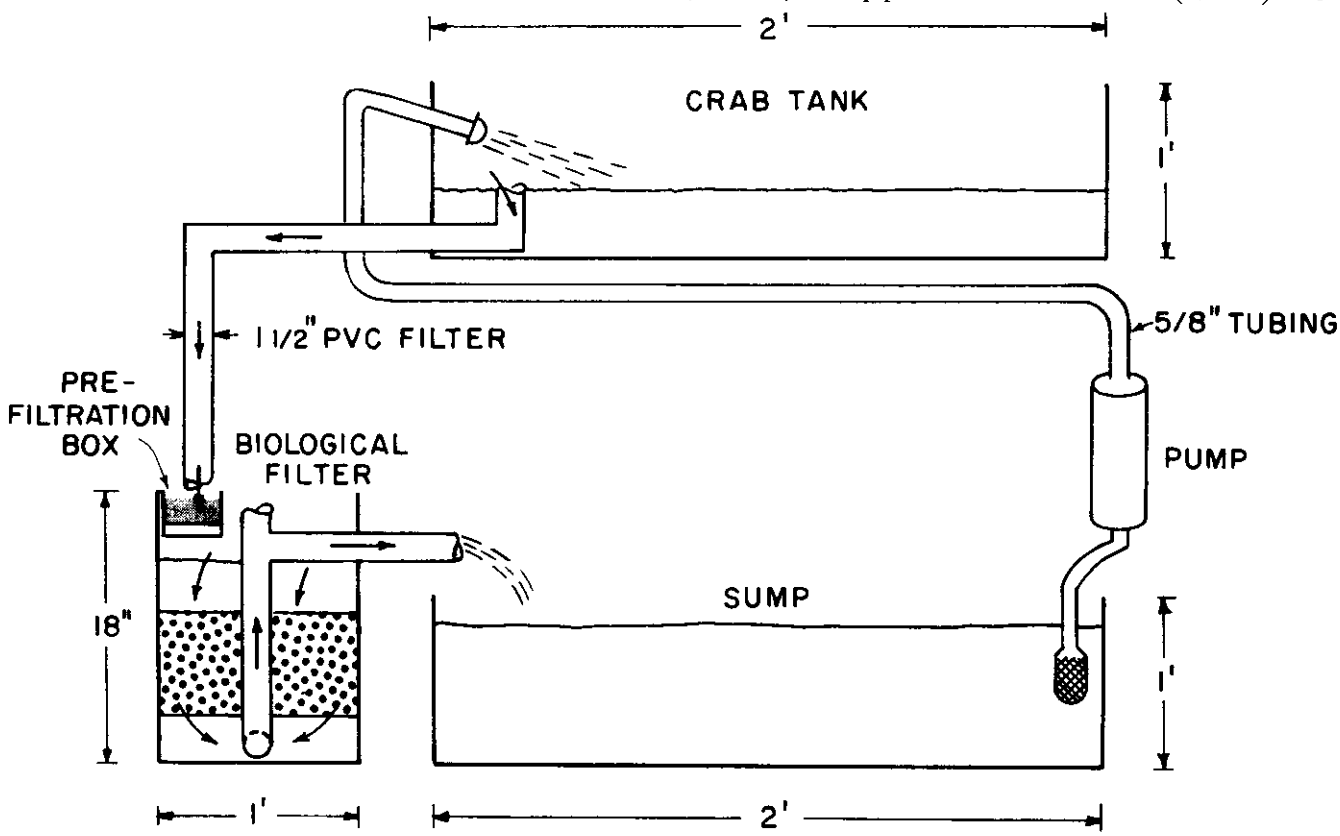

Figure 2. Configuration of experimental crab-shedding systems.

pipe with gravity feed to the biological filter. The discharge nozzle into the upper tank consisted of a capped 0.5 in. (1.3 cm) PVC pipe with two 0.125 in. (0.3 cm) holes to assure active agitation (aeration) in the tank. Crabs were placed on the clean tank bottom.

The submerged downflow biological filter was supported by 0.5 in. (1.3 cm) egg-crate louvering raised 2 in. (5.1 cm) from the bottom of the filter tank. Dolomitic limestone was chosen as the single media component because of its availability and buffering capacity. This substrate has proven itself in commercial operations and is readily available. Three media sizes were used in the six systems. Systems 1 and 6 used limestone in the 2- to 5-mm size, systems 2 and 5 used 5- to 10-mm size and systems 3 and 4 used media in the 13- to 20-mm size. Each rock bed was 6 in. (15.24 cm) deep including a 1-in. (2.54 cm) support bed of No. 67 limestone so the smaller media would not fall through the louvering. Modifications also consisted of mechanical filtration boxes placed before the biological filters. Prefiltration of suspended solids was accomplished by polyester aquarium filter floss placed in these boxes and changed daily.

Water flowed by gravity from the biological filter to the sump or reservoir tank. The sump (which evolved in the commercial systems to buffer rapid water-quality changes) held the filtered water until it was pumped to the crab tank. A 0.05 hp chemical-solution pump (Teel, model 1P677) circulated the water through a 5/8-in. (1.6 cm) flexible plastic tubing to the spray nozzle in the upper crab tank at a rate of 6.0 ℓ per minute.

All crabs used in the study were intermolt and ranged in size and weight from 10 to 15 cm across the carapace (top shell) and from 100 to 150 g, respectively. Following local commercial practice, crabs in the closed-shedding systems were not fed. Mortalities were removed continually and populations restored to constant levels once a day. Periodically, the entire population of crabs was replaced to prevent weakening of the animals by starvation.

Techniques and instrumentation used to measure the discussed water-quality parameters are listed in Table 3. Salinity was regulated at 4 ppt and temperature remained at 18° ± 1°C.

RESULTS

Filter Media Size

Figure 3 shows the ammonia and nitrite concentrations for systems 1, 2 and 3 during the study. Each system was started up with a constant population of 5 crabs. Figure 3 demonstrates the classical startup curves expected in these systems. As the crabs excreted ammonia (their primary nitrogen metabolite), ammonia concentrations increased in the systems. According to conventional theory, as *Nitrosomonas* sp. populations increased in the filter and consumed ammonia, concentrations of ammonia decreased and nitrite increased. *Nitrobacter* sp. became established in the filter and began to convert nitrite to the much less toxic nitrate. Each system took 37 days for the biological filters to acclimate to the 5-crab loading before dropping to baseline conditions (the safe operation zone defined in Figure 1).

TABLE 3.

Measurements taken and techniques.

Parameter	Instrument or Test	Reference
Total ammonia as NH_3-N	Orion 95-10 ammonia electrode/ Orion 701 A digital Ionalyzer	APHA (1980)
Nitrite as NO_2-N	Bausch and Lomb Spectronic 20, Spectrophotometer	Sulfanilamide-based colorimetric reaction APHA (1980)
Oxygen as O_2	Yellow Springs Instrument Co. Dissolved oxygen meter, Model 51	
Salinity	American Optical Refractometer	
pH	Mini (Model 47) pH meter	
Nitrate as NO_3-N	Modified Hydrazine Reduction	Spotte (1979)
Alkalinity as $CaCO_3$	Titration	APHA (1980)

On day 43, systems 1, 2 and 3 were increased to a population of 10 crabs. Each system showed minor transitory increases in ammonia and nitrite, but quickly returned to baseline conditions. On day 53, the population in these systems was increased to 20 crabs. Again the systems responded well, with only minor increases in ammonia and nitrite levels. As Figure 3 shows, the secondary transitory peaks increase slightly in size as the media size increases.

Bacterial and Chemical Addition

System 4 (Figure 4) was started up on day 12 with the addition of 250 mℓ of commercially available concentrated nitrifying bacteria (Microbe Master brand), which is typically used in industrial and wastewater plants to alleviate shock loadings and meet discharge regulations. On day 13, 5 crabs were added to the system. The classical startup curve occurred and the system reached stable conditions in 36 days. No marked decrease in startup time was observed using the inoculating bacteria. System 4 was loaded with 20 crabs on day 53, with the corresponding transitory increase in ammonia and nitrite concentrations. However, these increases were small, demonstrating the system was well acclimated.

System 5 (Figure 4) started up on day 11 with 12 mg/ℓ of ammonia chloride (NH_4Cl). On day 12, 250 mℓ of concentrated nitrifying bacteria were added to the system.

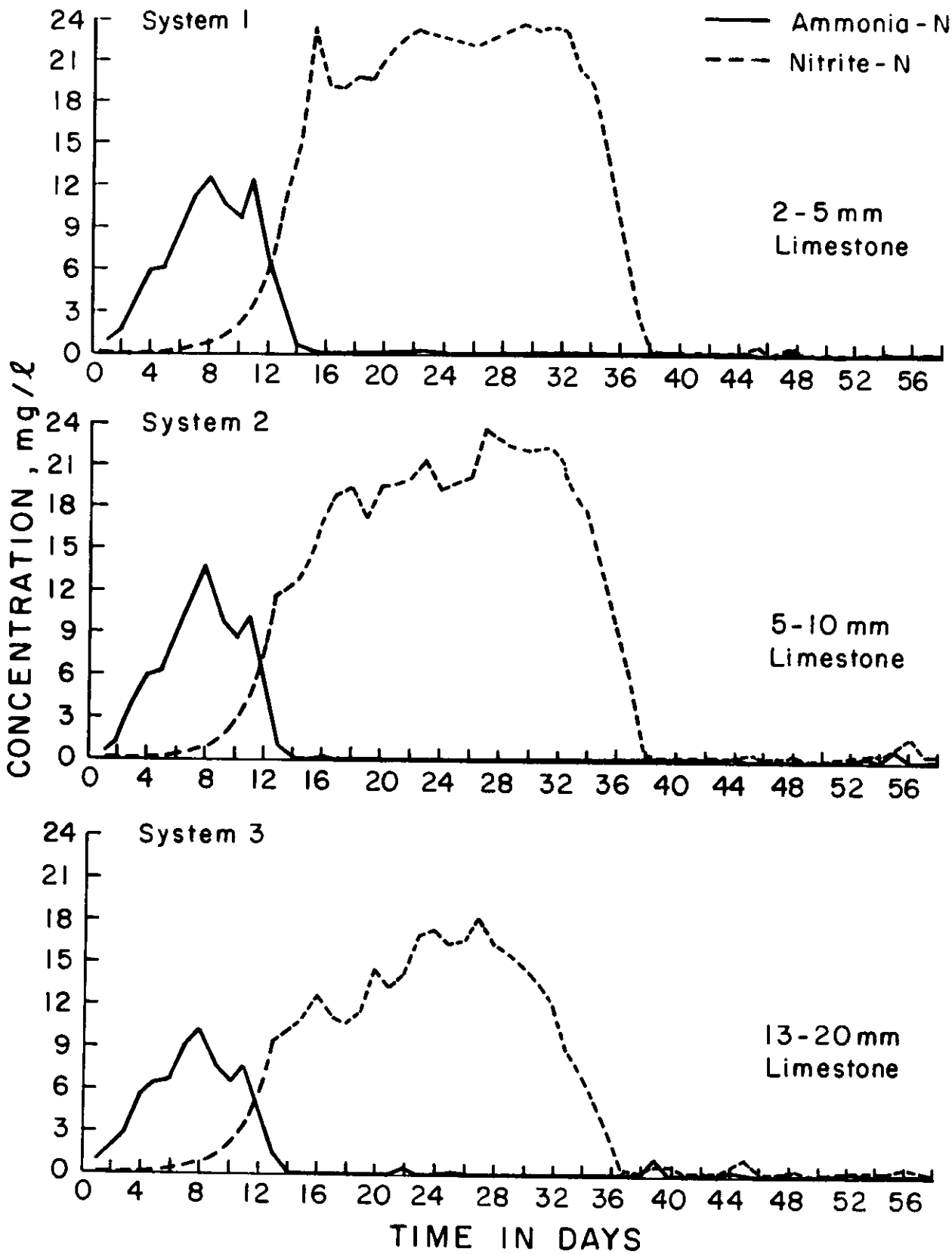

Figure 3. Filter acclimation curves of systems 1, 2 and 3 using three different media sizes.

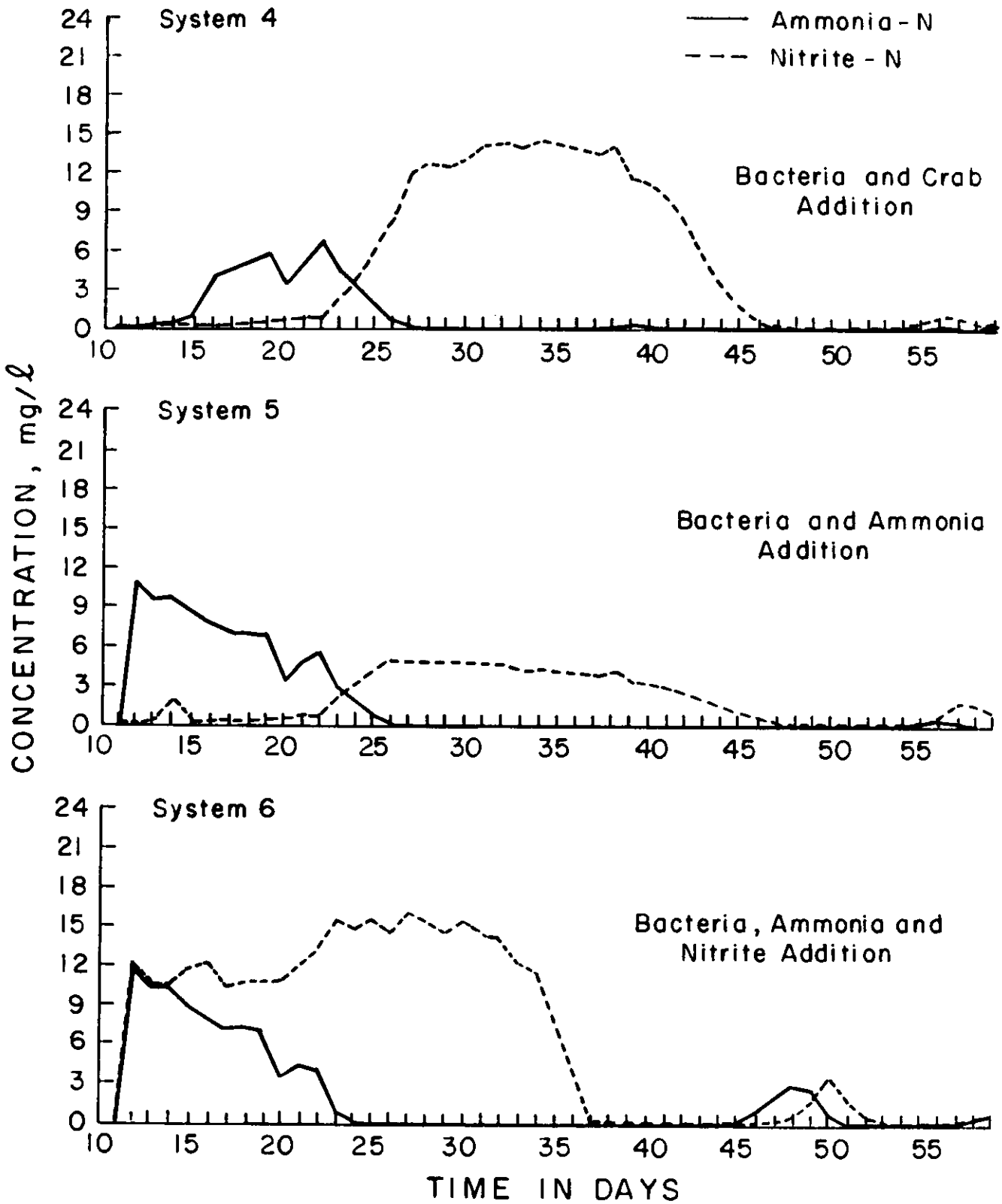

Figure 4. Filter acclimation curves of systems 4, 5 and 6 using commercial bacteria, and ammonia and nitrite addition.

Again the startup curve was produced and the system came to equilibrium in 37 days, demonstrating no decrease in startup time of the biological filter. Ten crabs were introduced to system 5 on day 53. Nitrite concentrations increased briefly to levels considered marginal, before returning to low-baseline ammonia and nitrite concentrations.

System 6 (Figure 4) was started up on day 11 with 12 mg/ℓ of ammonia chloride and sodium nitrite ($NaNO_2$). On day 12, 250 mℓ of concentrated nitrifying bacteria were added. The startup curve resulted and the system came to equilibrium in 26 days. Acclimation time of the biological filter was reduced by a full 10 days, suggesting that the combination of artificial ammonia and nitrite loading was beneficial. System 6 was loaded with 10 crabs on day 43 with the transitory ammonia and nitrite curves rising into the zone of marginal operation (nitrite concentrations approximately 3 mg/ℓ) for a period of 5 days before returning to baseline conditions.

DISCUSSION

Shock loading of commercial crab systems is a major problem at the beginning of the soft-shell crab season if the biological filters are not properly acclimated. In systems 1, 2, 3, 4 and 5, the biological filters took approximately 36 days to acclimate. The length of this conditioning period is consistent with the observations of Bower and Turner (1981), and significantly shorter than those of Hirayama (1974). However, differences in salinity, temperature, and loading regimes make direct comparisons difficult. Manthe et al. (1984) observed an acclimation time of 30 days in experimental crab-shedding systems. Salinities and loading regimes were similar, but temperature ranged from 12° to 23°C. Further study of temperature effects on the biological filter acclimation in crab-shedding systems should be undertaken.

In this series of experiments, systems 1, 2, 3 and 4 demonstrated the ability of crab-shedding systems, once acclimated, to handle increased loading by a factor of 4 within design constraints. These systems demonstrated the ability to acclimate to full-design loading (slightly less than 20 crabs) if acclimated with 25% of the design capacity (5 crabs) without any serious violation of the water-quality criteria suggested in Figure 1. Further research may demonstrate that fewer animals can be used in acclimation to achieve the same loading potential.

Biological filter media size had no effect on filter acclimation time. This was as expected by theoretical considerations because filter acclimation, in this stage, is limited by bacteria-generation time rather than available surface area of the media. As the systems were loaded to the design-loading capacity, the transitory ammonia and nitrite concentrations increased as media size increased. This seems to indicate that as crab loading reaches system design, one of the factors limiting bacterial growth rates is surface area of the media for the bacteria to colonize. However, during the startup of the filters, surface area is not a consideration.

Addition of concentrated nitrifying bacteria did not have any measurable effect on acclimation of the shedding systems. Probable reasons are bacterial shock due to induction into a foreign environment or the inappropriateness of the commercial additive bacteria for the biological filter in a crab-shedding system. This is consistent with the observations of Bower and Turner (1981) who tested three commercial additives and found no acceleration in the nitrification sequence in new seawater aquariums. Seeding of filters with substrate from established crab-system filters exposed to similar salinities is probably more appropriate.

Chemical acclimation with ammonia addition did not reduce startup time, but did acclimate the filter without using live animals. Addition of crabs after acclimation demonstrated the ability of the filter to adapt to loading under commercial conditions. This is advantageous because the operator can acclimate the system earlier in the season without the need for an animal supply. Furthermore, animals are not subjected to the detrimental water quality that is common during system acclimation.

Chemical acclimation using a combination of ammonia and nitrite decreased biological-filter acclimation time by 10 days. In this system the bacteria initially had a complete substrate to feed on. *Nitrobacter* sp. did not have to wait approximately 10 days to have enough nitrite to increase its population. Further research needs to be done in the area of artificial startup to prove this. The slightly higher response curves of chemical acclimation to crab loadings suggest that either the bacterial population in the system were deprived of substrate too long prior to crab introduction, or the filter population did not include the full complement of bacteria (due to artificial startup) to process crab waste. However, reliable and reduced acclimation time of filters in crab-shedding systems holds great promise. This would be most advantageous to a commercial crab-shedding system operator during the beginning of the shedding season when large peeler-crab harvests are prevalent.

CONCLUSIONS

1. In the loading regimes tested, the research team has found no significant effect of media size on acclimation time of the nitrification beds.
2. The commercial additive containing nitrifying bacteria had no significant effect on the ability of the biological filter to acclimate at a faster rate.
3. Addition of ammonia to stimulate loading of the system acclimated the biological filter, but did not shorten the time period needed for acclimation.
4. The most promising avenue of research is the addition of ammonia and nitrite in combination to stimulate growth in both species by nitrifying bacteria simultaneously. Nitrite addition during startup of a biological filter reduced the acclimation period by 28% (or 10 days).

ACKNOWLEDGMENTS

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REFERENCES CITED

APHA. 1980. *Standard Methods for the Examination of Water and Wastewater.* Washington, D.C.: American Public Health Association; American Water Works Association and Water Pollution Control Federation. 15th ed.

Bower, C. E. and Turner, D. T. 1981. Accelerated nitrification in new seawater culture systems: effectiveness of commercial additives and seed media from established systems. *Aquaculture* 24:1–9.

Hartenstein, R. 1970. Nitrogen metabolism in non-insect arthropods. Campbell, J. W. ed. *Comparative Biochemistry of Nitrogen Metabolism.* New York, N.Y.: Academic Press; Vol. 1:299–372.

Hirayama, K. 1974. Water control by filtration in closed systems. *Aquaculture* 4:369–385.

Jaworski, E. 1971. Decline of the softshell blue crab fishery in Louisiana. Environmental Quality Note 4. Available from: Texas A&M Univ., College Station, TX.

Manthe, D. P., Malone, R. F and Perry, H. M. 1983. Water quality fluctuations in response to variable loading in a commercial closed blue crab shedding facility. *J. Shellfish Res.* 3(2):175–182.

Manthe, D. P., R. F. Malone and Sunil Kumar. 1984. Limiting factors associated with nitrification in closed blue crab shedding systems. *Aquacultural Engineering* 3(2):119–139.

Mevel, G. and S. Chamroux. 1981. A study on nitrification in the presence of prawns (*Penaeus japonicus*) in marine closed systems. *Aquaculture* 23:29–43.

Perry, H. M., J. T. Ogle and L. C. Nicholson. 1982. The fishery for soft crabs with emphasis on the development of a closed recirculating seawater system for shedding crabs. Perry, H. M. and Van Engel, W. A., eds. *Proc. Blue Crab Colloquium.* 16–19 October 1979. 30th Annual Fall Meeting, Biloxi, Mississippi. Available from: Gulf States Marine Fisheries Commission, Ocean Springs, MS. 7:137–152.

Spotte, S. 1979. *Fish and Invertebrate Culture, Water Management in Closed Systems.* New York, N.Y.: Wiley-Interscience. 2nd ed.

Wheaton, F. W. 1977. *Aquaculture Engineering.* New York, N.Y.: Wiley-Interscience.

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985, 49–55.

ELIMINATION OF OXYGEN DEFICIENCIES ASSOCIATED WITH SUBMERGED ROCK FILTERS USED IN CLOSED, RECIRCULATING–AQUACULTURE SYSTEMS

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INTRODUCTION

The operation of a successful, closed, recirculating-aquaculture system depends on the maintenance of acceptable water quality. A submerged rock (biological) filter maintains optimum water quality by a series of biological and chemical processes. The biological filters addressed in this paper consist of dolomite and clam shell, upon which bacteria grew and extracted their nutrients and oxygen from water passing over the solid media. Theoretically, the biological (bacteriological) filter performed two main functions: mineralization and nitrification. Mineralization is the process of breaking down organics and proteins to form ammonia by general (heterotrophic) bacteria. Once organics have been converted to inorganic compounds, the process of concern was nitrification. The ability of biological filters in closed systems to convert ammonia (NH_3) to the relatively nontoxic nitrate (NO_3) by bacterial nitrification has been summarized by Wheaton (1977) and Spotte (1979).

The commercial potential of using closed, recirculating systems for the shedding of blue crabs has been undertaken by a number of crab fishermen (Perry et al. 1982, Manthe et al. 1983). However, the growth of the soft-shell industry has been retarded by the lack of established closed-system design criteria for shedding systems (Ogle et al. 1982). Manthe et al. (1984) identified toxic accumulations of nitrite as the factor limiting crab densities in crab-shedding systems. Intermolt crabs were adversely affected by nitrite levels in the vicinity of 20 mg N/ℓ and molting crabs by levels as low as 2 mg N/ℓ. Failure of the biological filter to provide rapid oxidation of ammonia and nitrite was attributed to a dissolved oxygen limitation in the filter. Higher mortalities resulting from nitrite accumulations aggravated the oxygen deficiency in biological filters and further affected system performance by contributing to the buildup of toxic nitrogen compounds.

One of the major constraints on submerged biological filters was their limited capability of supplying oxygen to support mineralization and the nitrifying processes. Under the assumption that oxygen will be the primary factor controlling the carrying capacity of a filter bed, a quantitative filter-design approach can be developed. The objective of this study was to develop such a quantitative approach to evaluate biological-filter designs for closed, recirculating crab-shedding systems.

DATA BASE

During the summer of 1983, six blue crab (*Callinectes sapidus* Rathbun) shedding systems were monitored in LaCombe, LA. Of the six systems, four scale-model systems were subjected to strict experimental control (Manthe et al. 1984). The other two systems monitored were full-scale commercial systems operated by the owner without interference by the authors (Manthe et al. 1983). Data presented in this paper were derived from these two papers (Manthe et al. 1983, 1984).

Figure 1 illustrates a schematic of one of the scale experimental systems. Each system consisted of two fiberglass tanks with a length, width, and depth of 6-, 3-, and 1-ft, respectively. Of the two tanks used in each scaled down system, the upper tank was devoted to holding crabs, and the lower tank to the various filtration units. Water was recirculated through the system at a constant flowrate of 6 ℓ/min.

OXYGEN DEMAND RELATIONSHIPS

Using the assumption that oxygen may be the principal factor limiting rock-filter efficiency, one may use mass balance of dissolved oxygen (DO) as a technique of computation. Oxygen consumption by bacterial conversion of nitrogen in a closed recirculation system is not restricted to the biological filter. However, because the surface area available for growth and attachment in the filter is very large in comparison to the other components, it is assumed that the major portion of the bacterial population is present inside the filter. Much of the following has been developed from principles presented by Hirayama (1965 , 1974). Hirayama advocated that oxygen consumed during filtration might be used as an index to indicate the degree of water purification for aquaculture systems in a manner similar to the way that biological oxygen demand (BOD) has been historically used in the stream sanitation studies.

For our original experimental configuration (Figure 1), oxygen consumed through the flowthrough filter was computed by the relationship

$$OCF = Q * (C_i - C_o) \quad (1)$$

where OCF = oxygen consumed in filtration (mg O_2/day); Q = flowthrough filter (ℓ/day); C_i = filter influent oxygen concentration (mg O_2/ℓ); and C_o = filter effluent oxygen concentration (mg O_2/ℓ). Thus, oxygen consumption in a submerged-rock filter for bacterial conversions was a direct function of the flowrate and the dissolved-oxygen concentration at entry and exit.

Assuming that a minimum DO concentration of 2.0 mg/ℓ was required to prevent inhibition of nitrifying bacteria (Gaudy and Gaudy 1978), the oxygen-carrying capacity of a filter may be given by:

$$OCC = Q * (C_i - 2.0) \quad (2)$$

where OCC = oxygen-carrying capacity of filter (mg O_2/day). The oxygen-carrying capacity (OCC) is the maximum amount of oxygen that can be consumed in the filter in a day, given the flow and influent DO concentration. For successful operation, the amount of oxygen made available to the filter (OCC) should always be greater than the oxygen demand on the filter (OCF).

The oxygen demand on the filter on a per-organism-basis can be computed empirically by the relationship,

$$OLR = OCF/N \quad (3)$$

where OLR = oxygen loading rate for organism (mg O_2/organism-day); and N = number of organisms in the system.

It is important to recognize that the OCF is not constant and varies considerably depending upon the conditions in the aquaculture system at the time of determination. Thus, loading rates should be derived from a substantial number of OCF observations.

Estimation of the theoretical carrying capacity of a given filter consisted of the quotient of determination of the oxygen-carrying capacity of the filter (Eq. 2) and a suitable approximation of the oxygen-loading rate (OLR) for the organism cultured (Eq. 3). The following equation may be used to determine the theoretical organism-carrying capacity of any given filter in terms of oxygen demand:

$$FCC = OCC/OLR \quad (4)$$

where FCC = filter-carrying capacity (organisms).

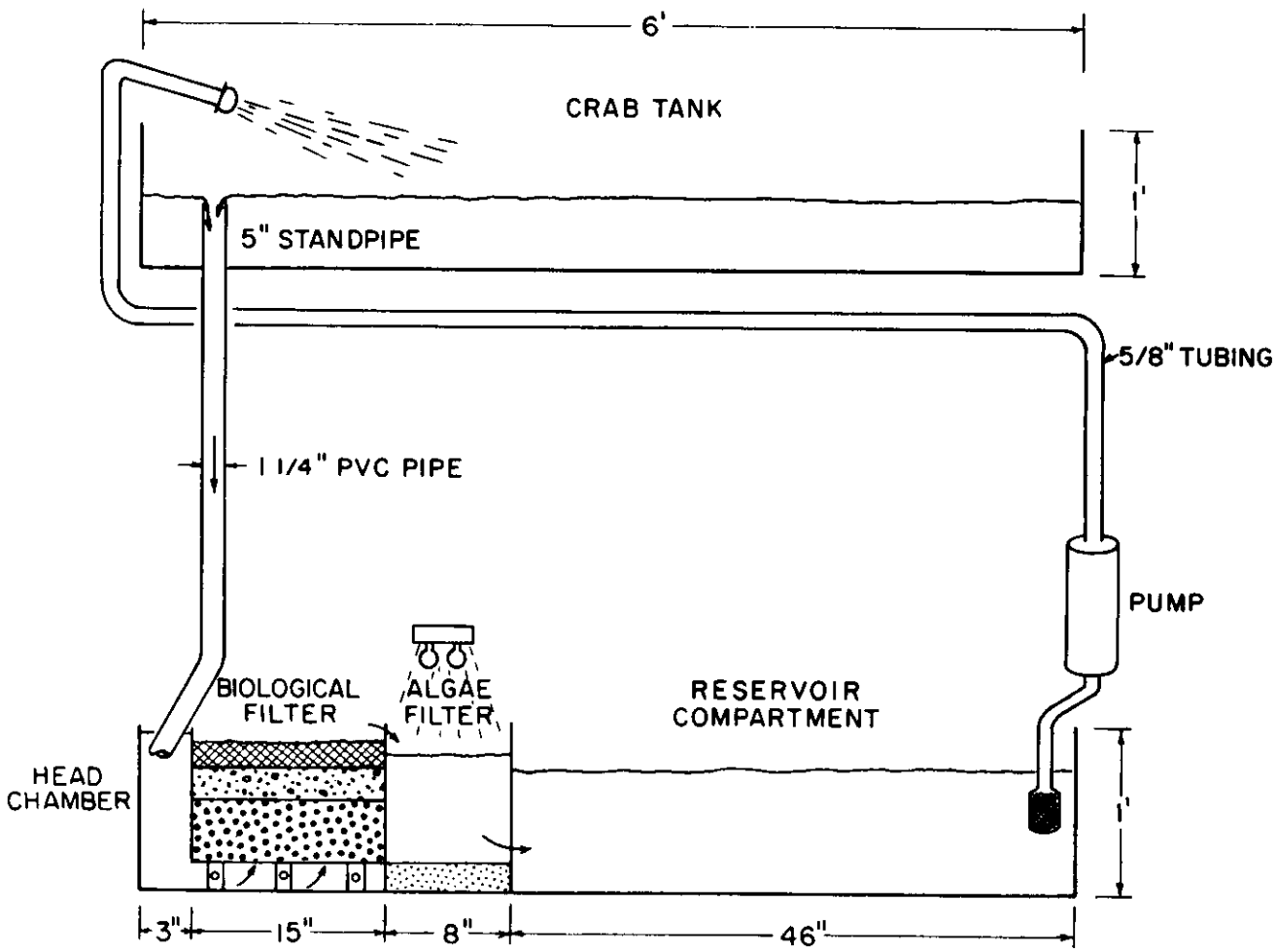


Figure 1. Configuration of experimental units.

Equations 3 and 4 have been developed assuming that substrate, temperature, salinity and pH are nonlimiting. As soon as one of those parameters starts to limit the nitrification process, the equations cease to hold.

Using the equations derived above and assuming DO limitation in the biological filter, various approaches will be considered to alleviate this deficiency in crab-shedding systems.

EVALUATION OF BIOLOGICAL FILTER DESIGNS

To make quantitative comparisons of filters in terms of oxygen, other assumptions have to be imposed. All of these assumptions are supported by data from experimental crab systems (Manthe et al. 1983, 1984) and various literature. These assumptions are presented in Table 1. It has been assumed that temperature is not allowed to rise above 30°C with an upper bound of 5 ppt imposed on salinity. This matches conditions experienced by commercial soft-shell producers in Louisiana. pH is assumed to be constant and in the range of 7.0 to 8.5, an acceptable range for nitrification efficiency (Wheaton 1977). For comparison purposes, the absolute volume of the filter is a constant 0.047 m^3 with a mean media-particle size of 2 cm in diameter. Surface area is assumed not to be a limiting factor. Calculations, using media size and historical filter-removal rates, determined that a filter with this volume theoretically can support over 1,000 crabs by surface-area considerations alone (Kumar 1984).

TABLE 1.

Assumed operating conditions for theoretical filter evaluation.

Parameter	Assumed Operating Condition
Baseline flow rate	6 ℓ/min.
Temperature	<30°C (86°F)
Filter volume	$=0.47$ m (1.72 cu ft)
Mean media diameter	$=2$ cm
Salinity	<5 ppt
pH	between 7.0 and 8.5
Dissolved oxygen concentration*	
Unaerated influent	$=0.7 \times 7.33 = 5.13$ mg/ℓ
Aerated influent	$=0.8 \times 7.33 = 5.86$ mg/ℓ

*Saturation oxygen concentration at 30°C and 5 ppt salinity = 7.33 mg/ℓ

For calculation of OCC, the saturation oxygen concentration at 30°C and 5 ppt salinity is 7.33 mg/ℓ (Spotte 1979). For unaerated water, the influent DO concentration is assumed to be 70% of the saturation oxygen concentration; for aerated water, the influent DO concentration is assumed to be 80% of the 7.33 mg/ℓ value. The base flowrate is a constant 6.0 ℓ/min.

The OLR was calculated for the experimental crab systems using only data points where the exit DO concentration was greater than 2 mg/ℓ to ensure that the total OLR was being expressed and not limited by an oxygen deficiency. Figure 2 illustrates the distribution of oxygen comsumption in the biological filters on a per crab basis derived from Manthe et al. (1984). The mean loading rate (based on 9 observations) was found to be 498.8 mg O_2/crab/day with a standard deviation of 29.3 mg O_2/crab/day. To estimate the crab-carrying capacity of the filter, it is assumed that the OLR is 500 mg O_2/crab/day.

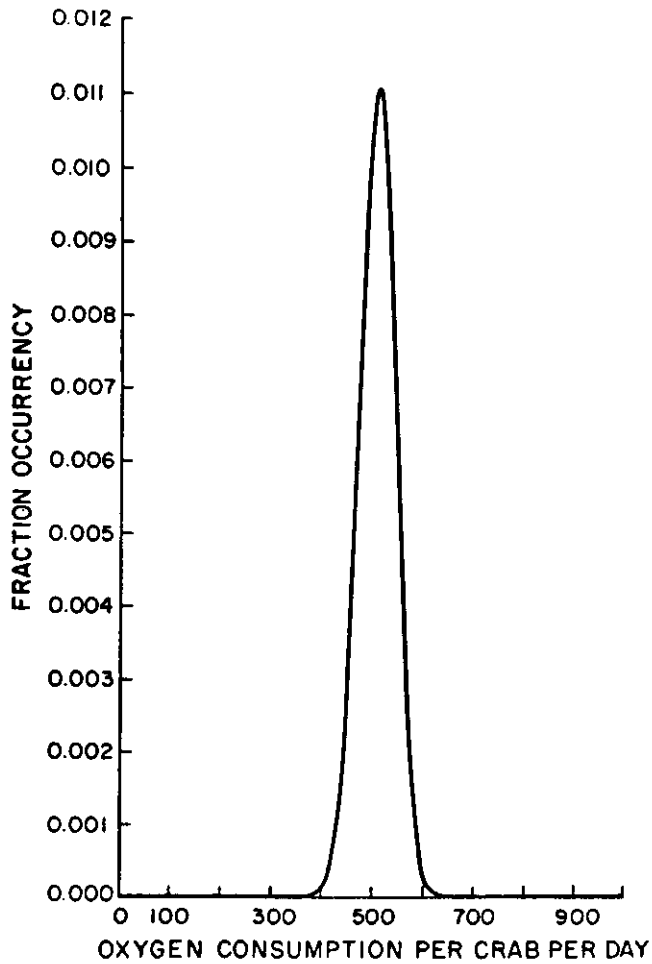
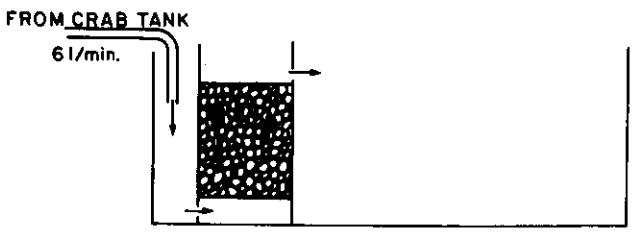


Figure 2. Distribution of oxygen consumption in the filter on a per crab per day basis.

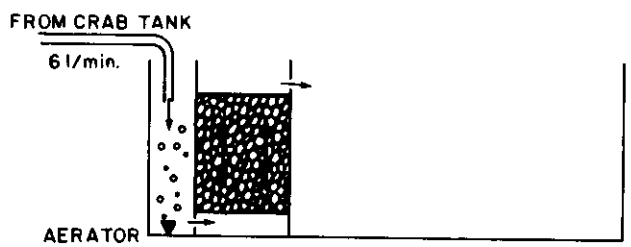
Three biological filter configurations used in experimental crab systems by Manthe et al. (1984) are presented in Figure 3. Expressions governing the oxygen-carrying capacity (OCC) to determine the filter-carrying capacity (FCC) in terms of crabs, and a schematic diagram for each filter is shown in Table 2.

Design 1 represents an unmodified submerged upflow filter design as presented in Figure 1. The oxygen-carrying capacity for this design can be directly calculated from Eq. 2, assuming the influent dissolved-oxygen concentration is at 70% of saturation. The crab-carrying capacity of this design was theoretically estimated to be 54 crabs when operating under the imposed conditions. Manthe et al. (1984)

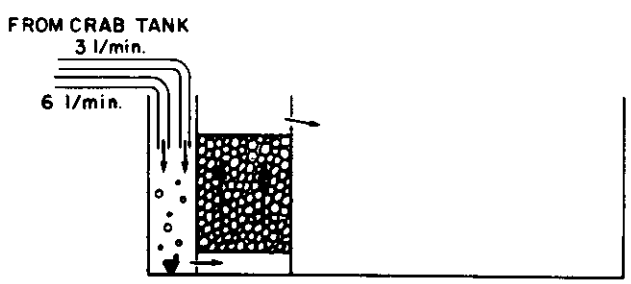
determined by field experiments that this design would easily support 50 crabs, but the design failed when the population was increased to 75 crabs. Thus, the calculations were found to be consistent with field observations.



DESIGN 1: SUBMERGED UPFLOW FILTER



DESIGN 2: SUBMERGED UPFLOW FILTER WITH ADDED AERATION



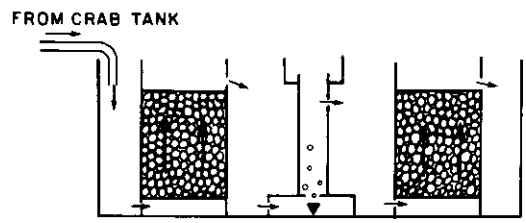
DESIGN 3: SUBMERGED UPFLOW FILTER WITH ADDED AERATION AND FLOW INCREASE

Figure 3. Filter configurations used in experimental crab systems.

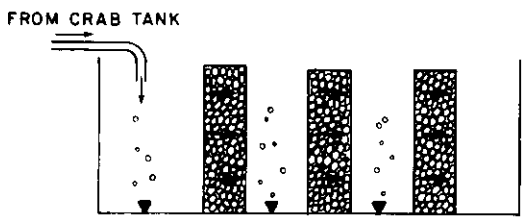
Design 2 is identical to design 1 except that the influent water is aerated before entering the filter. Equation 2 can be applied to this design in unmodified form, but the influent DO level is assumed to increase to 80% of saturation as a result of the aeration in the head chamber. Manthe et al. (1984) found this design could not support 75 crabs in field experiments. The calculated theoretical-carrying capacity was determined to be 66 crabs. The oxygen-carrying capacity can be seen to have increased only slightly as the result of aeration. This design modification is seen to be of very limited value because aeration did not elevate the DO concentration of the influent water higher than the saturation concentration.

Design 3 is identical to design 2 with an increased flow-rate (6 ℓ/min. to 9 ℓ/min.) through the filter by means of an auxiliary recirculation pump. Experimental observations on this design showed that the filter could easily support 75 crabs. By theoretical calculations, this filter design was capable of carrying 100 crabs. The filter-carrying capacity of this submerged upflow design was improved by 50% as a result of aeration and flow increase. These results indicated that a combination of aeration and flow recirculation could significantly impact the OCC of a biological nitrification bed.

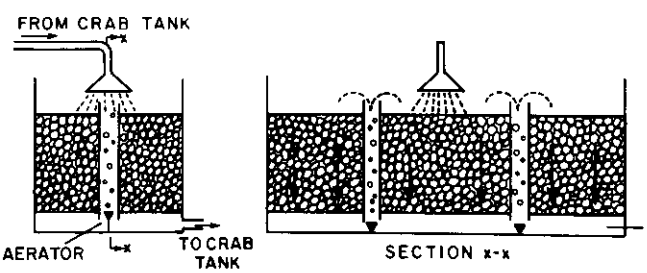
Based on the previous evaluation, three alternative filter designs were selected for further theoretical analysis and are presented in Figure 4. Expressions governing the oxygen-carrying capacity of the theoretical filter designs are included in Table 3.



DESIGN 4: TWO FILTERS AND A FOAM FRACTIONATOR



DESIGN 5: COMPARTMENTALIZED FILTER



DESIGN 6: DOWNFLOW FILTER WITH TWO AIRLIFT PUMPS

Figure 4. Alternative filter configurations selected for theoretical analysis.

Design 4 represents a filter design used by soft-shell crab system operators in the Chesapeake Bay region (Oesterling 1984). In practice, two biological filters are used with a foam fractionation unit between them. The effluent from the first filter will have a low DO content that the foam fractionator coincidently aerates before the water passes through the second filter. The ability of the foam fractionator to remove dissolved organics and, in turn BOD, was

TABLE 2.

Expressions governing the oxygen-carrying capacity (OCC) and filter-carrying capacity (FCC) of filter designs used in experimental crab systems.

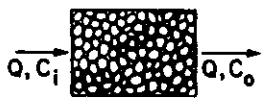
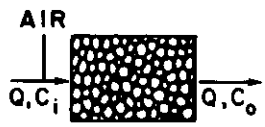
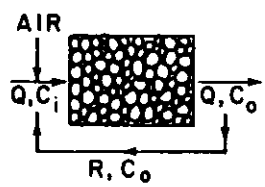
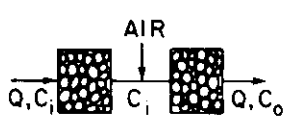
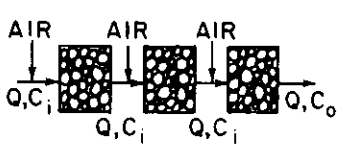
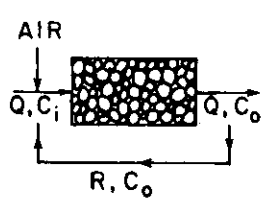
FILTER	SCHEMATIC	GOVERNING EXPRESSION (for oxygen carrying capacity)	FILTER CARRYING CAPACITY (CRABS) (calculated under given conditions)
1. SUBMERGED UPFLOW		$Q * (C_i - C_o)$	54
2. SUBMERGED UPFLOW WITH AERATION		$Q * (C_i - C_o)$	66
3. SUBMERGED UPFLOW WITH AERATION & RECIRCULATION		$(Q + R) * (C_i - C_o)$	100

TABLE 3.

Expressions governing the oxygen-carrying capacity (OCC) and filter-carrying capacity (FCC) of alternative filter designs selected for theoretical analysis.

FILTER	SCHEMATIC	GOVERNING EXPRESSION (for oxygen carrying capacity)	FILTER CARRYING CAPACITY (CRABS) (calculated under given conditions)
4. DUAL FILTER		$Q(C_i - C_o) + Q(C_i - C_o)$	120
5. COMPARTMENTALIZED FILTER		$\sum_{j=1}^{n} Q(C_i - C_o)$	200
6. AIRLIFT		$(Q + R)(C_i - C_o)$	438

neglected in this analysis. It was assumed that the foam fractionator acted primarily as an aeration device. Equation 2 was modified to reflect the serial operation of the dual filter system. The total oxygen-carrying capacity was computed from the summation of the OCC of individual components. The theoretical filter-carrying capacity was significantly increased to 120 crabs under the imposed assumptions. Perhaps, the increased oxygen supply from this placement of the foam fractionator explains, in part, the early success of these dual-filter systems.

Design 5 is a horizontal flow system consisting of the filter volume broken into three thin walls of media with aeration between each wall. Because surface area was assumed to be nonlimiting, this design acted as three independent filters operating in series. Thus, the oxygen-carrying capacity was calculated by summing the individual filters. Similar compartmentalized filters were used in clam and oyster studies in Delaware (Srna 1975). The filter-carrying capacity was estimated to be 200 crabs.

Design 6 is a modified downflow filter design with two airlift pumps. The airlift standpipe served two purposes; it promoted a high recirculation rate in the filter and aerated the filter effluent during recirculation. The recirculation flowrate through the airlift unit is given by the following expression (Spotte 1979):

$$R = (0.758 * S^{1.5} * L^{0.33} + 0.01196) * D^{2.2} * N \quad (5)$$

where R = recirculation flowrate; S = submergence ratio; L = length of standpipe (cm); D = pipe diameter (cm), and N = number of standpipes.

The maximum recycle flowrate was calculated to be 32 ℓ/min. with two standpipes with a length of 25 cm, pipe diameter of 2.5 cm, and the submergence ratio of 1.0 (completely submerged). The theoretical filter-carrying capacity of this design was estimated to be 438 crabs under the assumptions of this analysis. The estimated carrying capacity, however, exceeded the practical limits of our assumptions. An experimental system, such as that illustrated in Figure 1, loaded with this number of crabs would quickly clog with excessive bacterial growth. pH limitations also would appear in response to increased acid production by higher crab populations, as the pH in the entire crab system is regulated by the dissolution of the calcium carbonate filter bed. These calculations, however, clearly illustrated the great ability of the airlift design to eliminate oxygen as a limitation in biological filters. In practice, physical clogging of filters and pH declines limited the carrying capacity of the experimental systems (0.047 m^3 of 2 cm substrate) equipped with airlift pumps to about 120 crabs.

DISCUSSION

This analysis revealed the superiority of a filter design incorporating a high flowrate and aeration. These processes substantially increased the amount of oxygen available for biological filter functions. Figure 5 illustrates two methods (designs 3 and 6) recommended for increasing the oxygen supply to the submerged biological filters. Airlift aeration used a standpipe and an airlift pump to recirculate and aerate water in the filter. Recycle aeration employed an auxiliary recirculation pump (or excess flow from the main pump) to spray water through an aeration head on top of the filter, thus increasing the flowrate. Either of these approaches could be used to enhance performance of an existing biological filter whose filter-carrying capacity (FCC) has been exceeded. For example, in preliminary tests conducted by the authors using design 6 with standpipes, the crab-carrying capacity of shedding systems was increased by 100% over design 1 before clogging of the filter bed and pH in the crab system became limiting.

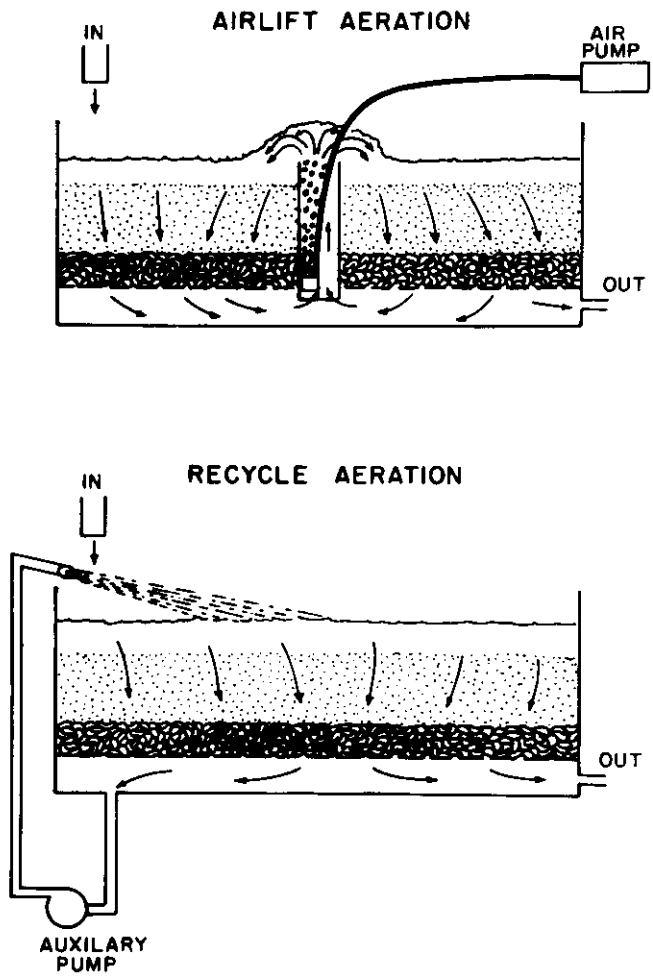


Figure 5. Two methods recommended for increasing the oxygen supply to submerged rock filters.

Although the multicompartment filters (designs 4 and 5) showed significantly increased oxygen-carrying capacities, in practice, they were often limited by physical clogging of the upstream components. The upstream component was subject to the highest waste concentrations and thus

displayed excessive bacterial growth if sufficient oxygen was provided (Srna 1975). Thus, designs which rapidly distribute the waste load throughout the filter (designs 3 and 6) are more desirable. It has been the the observations of the authors that multicompartment filters will function satisfactorily, however, if flow from a clogged compartment is allowed to bypass to subsequent compartments. This arrangement inherently permitted the distribution of waste loading during periods of peak loading, compensating for the tendency of multicompartment filters to clog.

Because the carrying capacity of a filter is inversely proportional to the oxygen loading rate on it, any reduction in the OLR could lead to an increase in the estimated carrying capacity. A well-maintained aquaculture system (no decaying organic materials present) will have a lower OLR and, therefore, a higher theoretical filter-carrying capacity. Removal of gross particulates and dissolved organics before the filter will decrease the OLR. This can be accomplished by using prefiltration techniques, such as mechanical filtration or a foam fractionator. Oesterling (1984) described commercial applications of each prefiltration technique. In the experience of the authors, the filter-carrying capacity can be increased by nearly 30% by prefiltration techniques.

This methodology for analyzing biological filters in terms of oxygen should be applicable to other closed aquaculture systems, if the oxygen consumed during filtration (OCF) under culture conditions is determined. The methodology described will provide a quantitative analysis of the oxygen supply and requirements needed for filter design of the particular aquaculture venture undertaken. A filter then can be designed and incorporated in the closed system which will meet the needs for oxygen in the most efficient and economical manner.

ACKNOWLEDGMENTS

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REFERENCES CITED

Gaudy, M. S. and Gaudy, E. T. 1978. *Microbiology for Environmental Engineers.* New York, N.Y.: Wiley-Interscience.

Hirayama, K. 1965. Studies on water control by filtration through sand bed in a marine aquarium with closed circulating system–I. Oxygen consumption during filtration as an index in evaluating the degree of purification of breeding water. *Bull. Jpn. Soc. Sci. Fish.* 31:877–892.

_____ . 1974. Water control by filtration in closed systems. *Aquaculture* 4:369–385.

Kumar, S. 1984. Closed recirculating nitrification systems for soft shell crabs. Baton Rouge, LA:Louisiana State University. Thesis.

Manthe, D. P., R. F. Malone and H. M. Perry. 1983. Water quality fluctuations in response to variable loading in a commercial closed blue crab shedding facility. *J. Shellfish Res.* 3(2):175–182.

Manthe, D. P., R. F. Malone and S. Kumar. 1984. Limiting factors associated with nitrification in closed blue crab shedding systems. *Aquacultural Engineering* 3(2):119–139.

Oesterling, M. J. 1984. *Manual for Handling and Shedding Blue Crabs.* Gloucester Point, VA: Virginia Institute of Marine Science, College of William and Mary.

Ogle, J. T., H. M. Perry and L. C. Nicholson. 1982. Closed recirculating sea water systems for holding intermolt crabs: literature review, systems design and contruction. *Tech. Rep. Ser.* 3:1–11. Available from: Gulf Coast Research Laboratory, Ocean Springs, Mississippi.

Perry, H. M., J. T. Ogle and L. C. Nicholson. 1982. The fishery for soft crabs with emphasis on the development of a closed recirculating seawater system for shedding crabs. Perry, H. M. and Van Engel, W. A. eds. *Proceedings of the Blue Crab Colloquium.* 16–19 October 1979. 30th Annual Fall Meeting, Biloxi, MS. Available from: Gulf State Marine Fisheries Commission, Ocean Springs, MS. 7:137–150.

Spotte, S. 1979. *Fish and Invertebrate Culture, Water Management in Closed Systems.* New York, N.Y.: Wiley-Interscience. 2nd ed.

Srna, R. F. 1975. A modular nitrification filter design based on a study of the kinetics of nitirification of marine bacteria. *Proc. 6th Annu. Mtg. World Maricult. Soc.* Baton Rouge, LA: Louisiana State University.

Wheaton, F. W. 1977. *Aquacultural Engineering.* New York, N.Y.: Wiley-Interscience.

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DESIGN CONSIDERATIONS IN MARINE AQUACULTURE SYSTEMS

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INTRODUCTION

There are many types of marine aquaculture systems ranging from extensive pond culture systems to intensive raceway and/or recycled systems. Because the focus of this conference is on recirculating blue crab shedding systems, this paper will emphasize recycled culture systems. Emphasis will be on system design aspects and on approaches that have been used by various people to resolve problems encountered in system operation.

Closed, recycled or recirculating systems may be defined as a system designed to hold or grow an aquatic crop in which the water is placed into the system and only changed infrequently. Theoretically, a totally recirculated system would never change the water and water would be added only to replace evaporative losses. Practical systems usually replace some portion of the water on each pass through the system, typically up to about 10% per pass.

Culture systems may be designed in an almost endless variety of configurations. However, the usual design includes a culture tank, which holds the desired organism to be cultured, a pumping system to recirculate the water, a water-purification system and a system to control gas concentrations. Figure 1 shows a block diagram of the typical system. Each block in Figure 1 will contain unit operations selected and sized for the specific system.

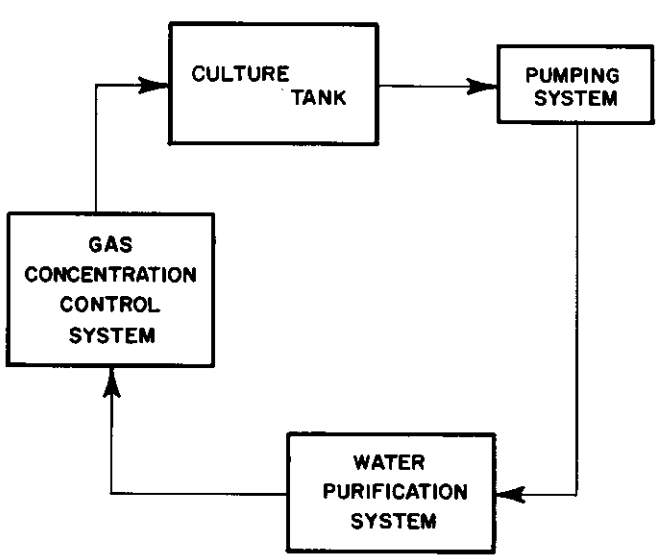

Figure 1. Typical culture system design.

A blue crab shedding system is an example of a closed cycle culture system (Figure 2). The system usually consists of one or more 4 ft × 8 ft × 10 in. deep culture tanks. Water flowing through these tanks must supply all environmental needs of the crabs. The crabs excrete wastes into the water that must be removed by the water purification system. A typical water purification system consists of a foam fractionator, which removes surface active compounds, and a biological filter which converts ammonia to nitrite and then to nitrate. The gas concentration control system is some type of aerator which adds oxgen and removes excess carbon dioxide.

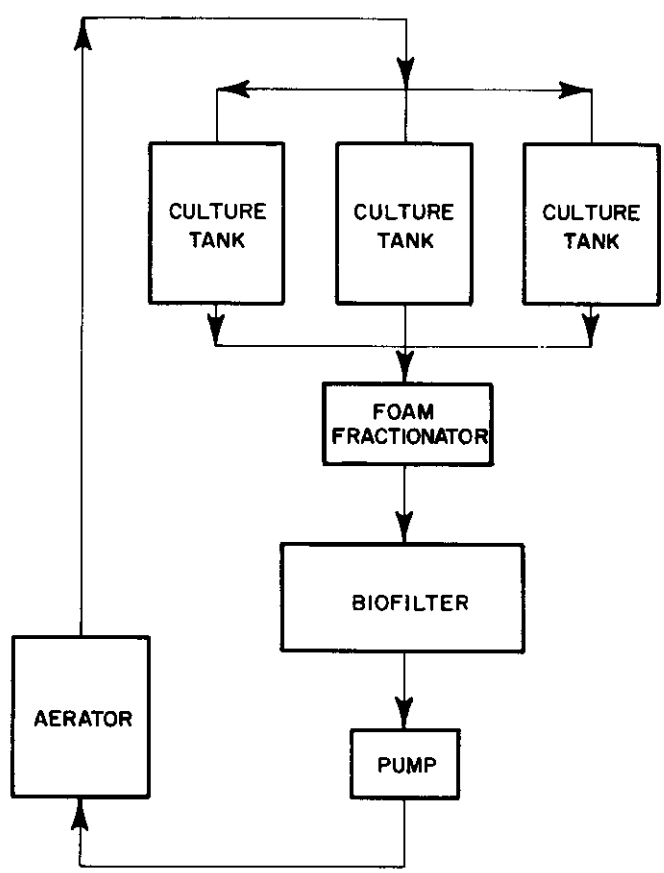

Figure 2. Typical closed cycle blue crab shedding system.

The final design of any culture system must be done as a system and not as a group of individual components. Designing components independent of the total system will

result in components that will not match each other. When this occurs the system often fails. Underdesign of a component (i.e., the component is too small) will lead to system failure. Overdesign of a component (i.e., the component is too large) is not only expensive but may also cause system failure. This latter point is often not apparent to inexperienced designers.

Although system components cannot be designed independent of the total system, it is instructive to discuss the basic components separately to illustrate several design considerations.

CULTURE TANK

The culture tank is where the money is made or lost and often is the part of the system receiving the most attention. Unfortunately, the attention given to the culture tank often is a visual inspection. If the crabs are dying it is immediately obvious. However, proper monitoring of the culture tank with instruments that measure parameters our eyes are not sensitive to, may have prevented the mortality and/or even the stress on the animals. The human eye and nose are excellent sensors for some things, but may be insensitive to those parameters detrimental to the cultured animals.

Environmental Needs

Water flowing through the culture tank must supply a survivable and hopefully nonstressful environment for the cultured organism. Thus, the first prerequisite for design is knowing what environment must be provided. The designer must depend heavily on published scientific literature for this information. Laboratory studies may have to be set up to determine parameters that are not available in the literature.

The manner in which environmental data is reported in the literature will present the designer his first challenge. Temperature data are a typical example. The LD_{50} for 24, 48, 96 hours, or some other time period for a fish species is a common method of reporting temperature tolerance. A 96-hr LD_{50} of 25°C means that tests were conducted on fish acclimated to some temperature, say 20°C. These fish were placed into tanks of water held at 25°C and the fish were observed. The result of the test was that 50% of the fish in the 25°C tank were dead due to thermal stress after 96 hr. LD_{50} tests can be carried out in the laboratory with a reasonable amount of time, cost and effort. However, from the design standpoint LD_{50} data are of limited value. Designing the system to operate at 25°C is clearly going to result in 50% of the crop dying in 4 days, not a very profitable outlook. Thus, the system must operate below 25°C. The LD_{50} data tell the designer nothing about how much below.

Most aquatic animals cultured today are cold blooded (i.e., their body temperature changes with the environmental temperature). Because their metabolic processes operate more rapidly at higher temperatures, at least up to the thermal-stress temperature, it is desirable to design systems for as high a temperature as is economically feasible. The LD_{50} data will not define the most desirable temperature.

Several approaches are available to help the designer. The thermal polygon is one such approach (Figure 3). The zone of resistance (Figure 3) is that set of acclimation and ambient temperatures in which the organism can survive for a short period but not indefinitely. In the zone of tolerance the organism can survive indefinitely, but the zone where reproduction and other activities can occur may be even smaller. The areas designated as instantaneous death are the temperature combinations in which the organism will die almost immediately upon being placed in that ambient temperature.

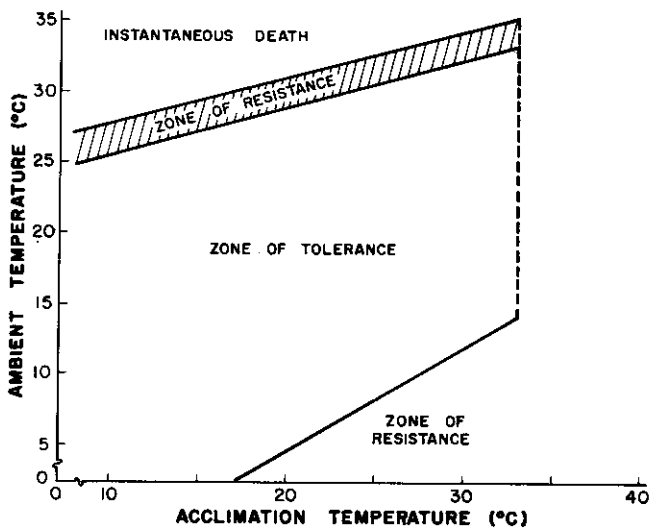

Figure 3. Temperature tolerance diagram.

Determining the edge locations of the zone of resistance requires considerable laboratory work. This can be accomplished by developing a graph as shown in Figure 4. The survival curve for each acclimation temperature will at some point become horizontal. The ambient temperature where this occurs is the location of one point on the edge of the zone of tolerance. The temperature polygon supplies the designer with much more information, in comparison to the LD_{50} approach, but is costly to develop. Insufficient data are available to develop a temperature polygon for the blue crab.

Although the temperature polygon approach is much more useful to the aquatic culture system designer than the LD_{50} approach, it treats each individual variable as a separate unit. Environmental variables, such as temperature, oxygen, food, etc., often have additive, multiplicative or other interactive affects on living organisms. For example, organisms held in temperatures high enough to cause stress cannot withstand as low an oxygen concentration as they could if there was no temperature stress. Thus, from a

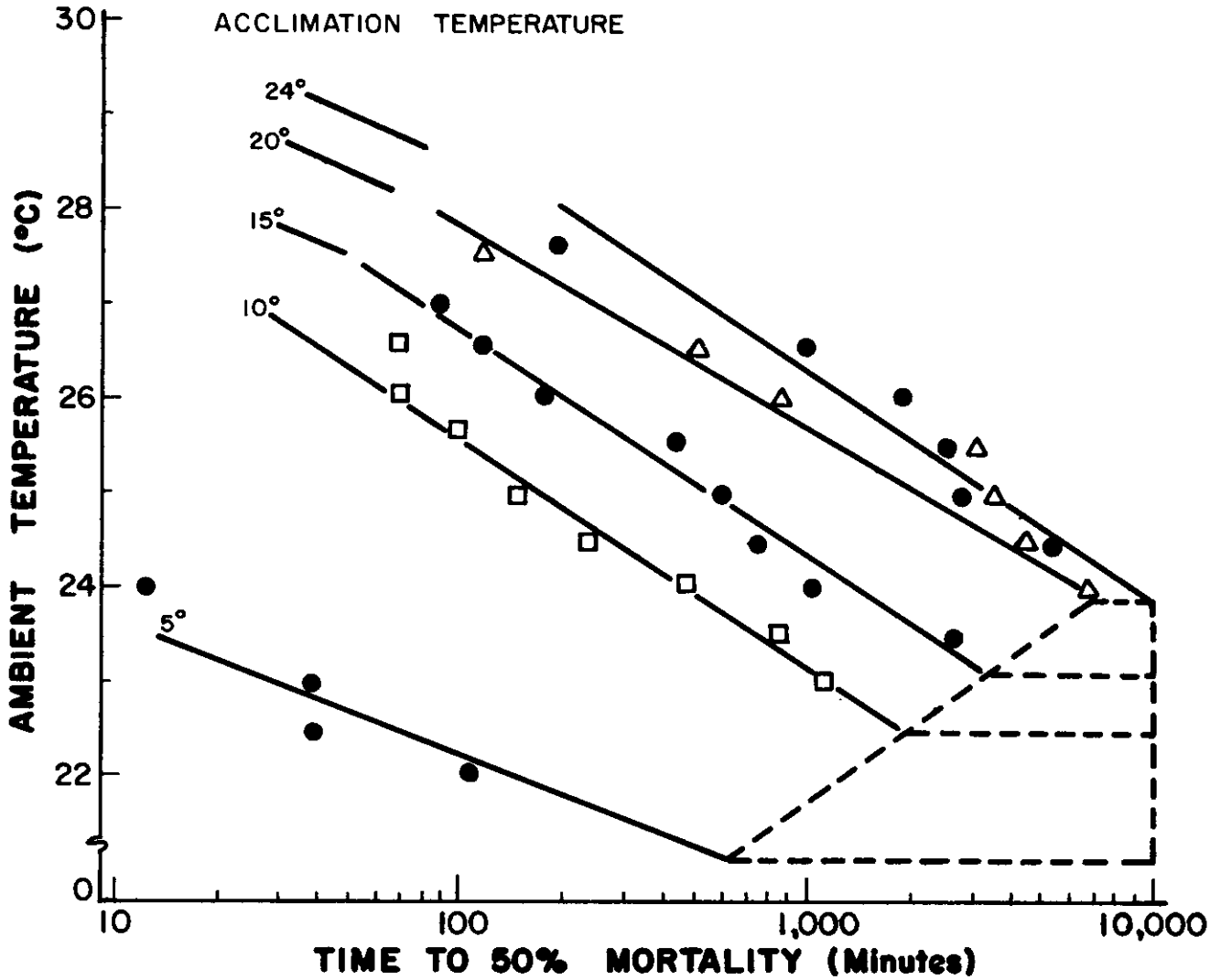

Figure 4. Median resistance times to high temperatures for young pink salmon acclimated to various temperatures (from Brett 1952).

design standpoint it is desirable to have a multivariate approach. With this appraoch the desired parameter is selected (e.g., growth rate). This parameter is treated as a dependent variable and all environmental parameters are treated as dependent variables. Tests are carried out to develop a response surface from which the growth rate can be predicted using any set of environmental variables. Mathematically, the response surface is described by an equation that may or may not be a polynominal as shown below:

$$y = a + b_1X_1 + b_2X_1^2 + b_3X_2 + b_4X_2^2 + \ldots + b_{2n-1}X_n + b_{2n}X_n^2$$

An experimentally developed equation may also have exponential or higher power terms in addition to or in place of some of the terms above. There may also be interaction terms of the form X_1X_3, $X_a^2X_b$, etc.

The multivariate approach allows the designer to determine the optimal set or sets of environmental parameters. Additionally it provides a method of assessing the penalty that must be paid in growth rate (or other dependent parameter) when suboptimal environmental parameters are selected. For example, assume 22°C is the optimal temperature for organism y when used with a certain set of other environmental parameters. However, the system designer finds he can supply 17°C water without heating, but will have to heat all inflow if he designs for 22°C. From the multivariate equation he can determine how much the growth rate will be reduced by using a nonoptimal temperature. Using existing prices and costs, he can then determine if it is more economical to heat the water or accept the reduced growth rate.

The multivariate approach is not completely available for many species because all environmental variables affecting an organism often are not known or because the cost of collecting the necessary laboratory data to define the multivariate equation is prohibitive.

Delivery

Assuming the desirable environmental parameters are known, the environment within the culture tank must be controlled to provide the desirable level for each environmental variable. Control of any specific variable implies that it can be measured. It is difficult to maintain 20 ppt salinity if you have no way to measure salinity. The desired environment must be available in all parts of the culture tank. Short circuiting and other water circulation problems must be eliminated if a uniform environment is to be available throughout the culture tank(s). Dead areas, areas of poor circulation, effectively reduce tank size.

There are several systems used to maintain good circulation in crab shedding tanks. Figure 5 shows some of these. Figure 5A shows an overhead pipe with holes drilled in it that allows the water to spray onto the tank surface. The tank outlet is in the center of the tank. This system provides good aeration but has some problems getting good circulation throughout the tank, especially the tank corners. Figure 5B has the same outlet system as in Figure 5A, but the water inlets are located in diagrammatically opposed corners of the tank. The inlets are formed into nozzles which create a higher velocity. The water is aerated as it passes through the air prior to striking the water in the tank, while the increased velocity imparts a rotation to the water in the tank. This system improves circulation but does not totally eliminate dead areas, especially in the tank corners not having a water inlet. A third system used combines the overhead spray and corner nozzles in the same tank. The center standpipe outlet is used in this system also. Oxygen measurements (Hochheimer 1984) indicate that the combination system provides more uniform oxygen concentrations throughout each tank than either system alone. To this author's knowledge, there has not been a definitive tank circulation study done on soft-shell crab peeling tanks.

System designers have the option of placing culture tanks in series or parallel. Series connection causes water to flow from one tank to the next and finally to the filtration system. Parallel connection causes water to pass through one tank and back to the filtration system. Series connection causes the waste concentration to build up as it flows from tank to tank. Obviously, the input of the second tank receives the waste from the first tank and so on from tank to tank. Parallel connections prevent this waste accumulation, but usually require higher flow rates and increased pumping costs. Because both a series or parallel system have advantages and disadvantages, there is no generally "best" type of connection. The parallel or series connection decision must be made based on the individual system and how it will be operated.

PUMPING SYSTEMS

Pumping systems include pumps, valves, piping and related equipment. Its primary function is to circulate water through the other system components. Pumping system design requires an understanding of basic hydraulics, pump characteristics, and valves. Most people with reasonable mechanical ability can put a plumbing system together that will circulate the water. However, such systems are often oversized, hence more expensive than necessary, or undersized and do not function well. Incorrect pump selection is also a fairly common mistake, and may lead to a variety of problems. Attempts to choke fixed displacement pumps often lead to plumbing failures or burned out pump motors. Selection of the wrong pump may also lead to pump clogging problems, poor system performance or high maintenance costs.

Pumping systems used in closed cycle systems must be reliable. Heavily loaded systems may suffer from fatal oxygen depletions in as little as 15 min after a pump failure. Thus, a minimum requirement is that a replacement pump be kept on hand so a failed pump can be replaced in a few minutes. A 24-hr per day alarm system is often a worthwhile investment. Many alarm systems are available, but when selecting one be sure the alarm will **always** be heard by someone who can do something about the problem. The classic case is for an alarm to sound indicating a pump failure and the person supposed to hear it just left to make a delivery that will require two hours.

Another design often used has two pumps connected in parallel in the system. Each pump is capable of handling the entire system. A sensor in the pump discharge line senses pressure. If the pressure drops, signaling a pump failure, a control circuit turns on the second pump automatically and provides some type of indicator to alert the person in charge of the pump failure. Pump replacement can then be done at a convenient time.

The plumbing system also needs to be designed with culture system conditions in mind. Bacterial and algae growth occur in culture systems, sometimes in large quantities. These can block pipes, especially at discontinuities such as valves, connections, etc. It is a good idea to provide some means to clean this material out of the system, preferably without completely dismantling the system. Ports can be provided for mechanical cleaning. Periodic chlorination, continuous ultraviolet light treatment and other systems may also be used to control these fouling problems. In flow-through systems, particularly marine systems, fouling by barnacles, sea squirts and other organisms, can be a very serious problem. Fouling can block a 4-in. pipe in a matter of a few days in locations with moderate to severe fouling problems.

WATER PURIFICATION SYSTEM

Water purification is probably the most difficult system design problem in recirculating systems. Not only are there many unit processes to choose from, but each process has many design parameters. It is impossible to discuss here the many unit processes available. Thus, discussion will be

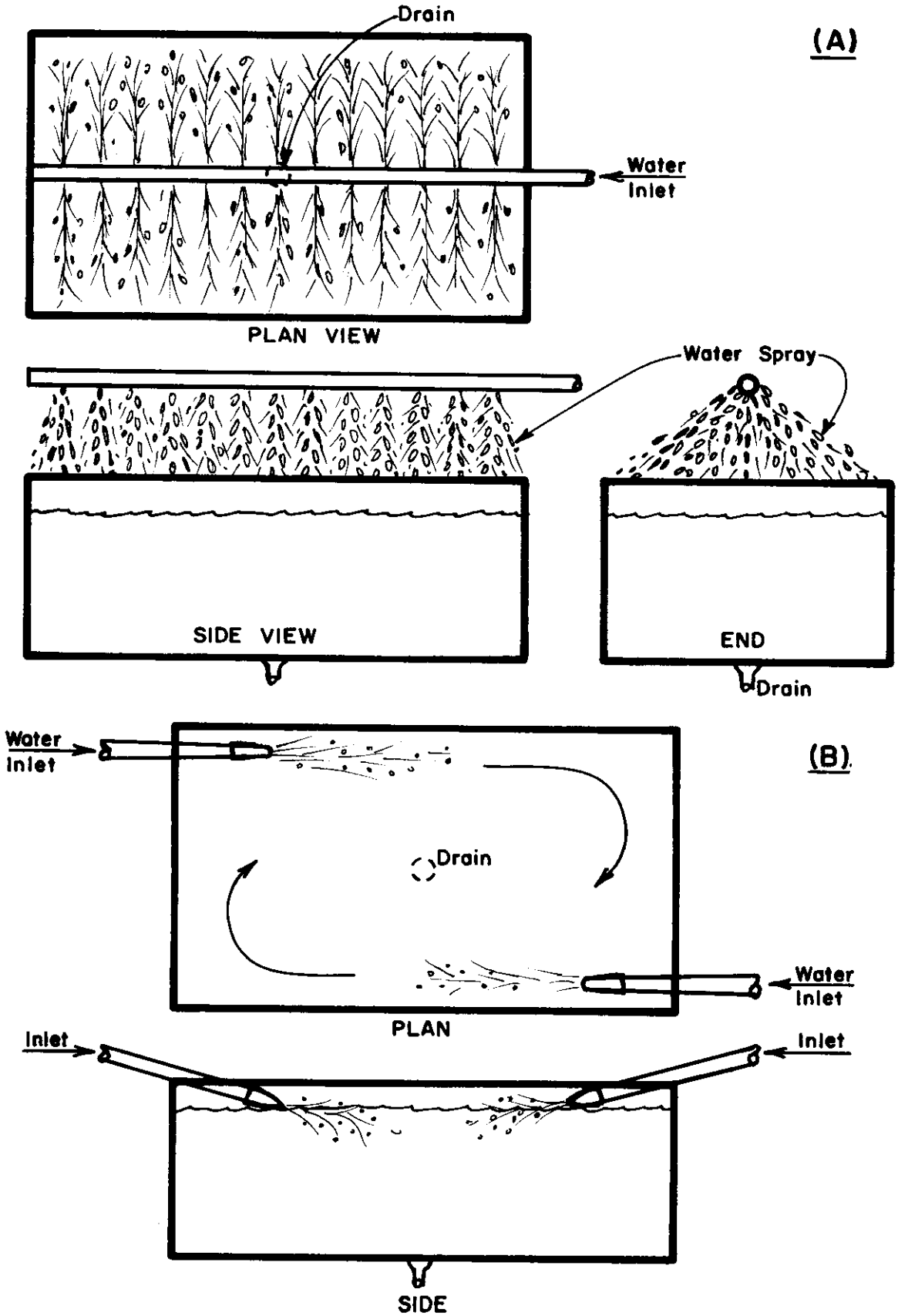

Figure 5. Crab tank circulation systems. (A) Overhead spray system. (B) Corner swirl pattern.

limited to those obviously applicable to crab recirculating systems with primary discussions focusing on foam fractionators and biological (nitrification) filters.

Foam Fractionation

Figure 6 shows a simple foam fractionator. The system consists of a vertical tube of some height and diameter. The liquid to be purified is mixed with air in a venturi and pumped through the fractionator column. The air bubbles rise through the liquid in the fractionator column and attract surface active compounds to their surfaces. As the bubbles leave the liquid and form a rising column of foam they take the collected surface active molecules with them. Discharge of the foam over the top of the fractionator removes the impurities from the liquid. The cleaned water (referred to as bottoms) leaves the fractionator at the bottom.

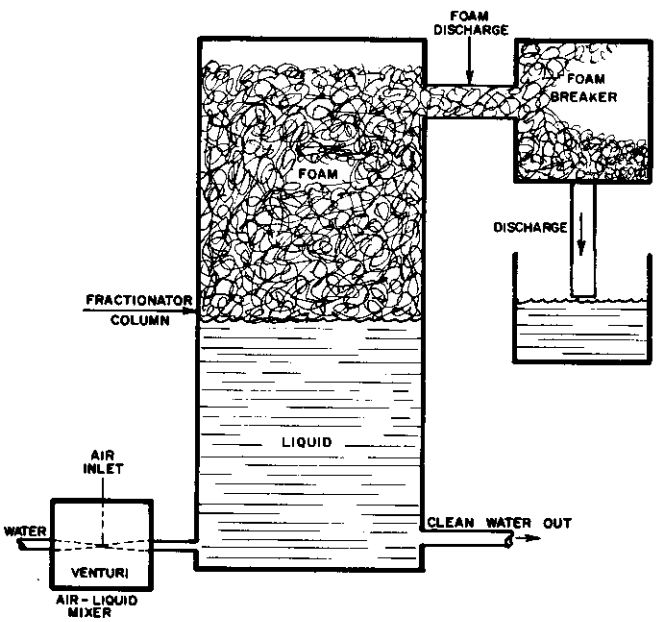

Figure 6. Simple foam fractionator.

Fractionator designs exist and are based primarily on experience. This author knows of no complete analytical design procedure for foam fractionators currently in existance. Foam fractionators have been used for over 40 years. Why isn't there any anaytical design procedure for them? At least 30 variables influence fractionator operation. Sorting out the influence of all of these variables on fractionator performance and converting it into a coherent design procedure is tremendously complicated, time consuming and costly.

Foam fractionators typically operate below a 20% per pass extraction efficieincy. Hence, on a one pass system they extract relatively limited quantities of the impurities. Water in a recycled system passes through a fractionator often and provides a much better opportunity for removal of the impurities.

Fractionators have been shown to remove BOD (Dwivedy 1973), surface active materials (Lush 1976, Lawson 1978), and some small particles. As a result of their metabolic activities, crabs and fish excrete materials into the water. Several of these materials (e.g., proteins, organic acids, etc.) have some surface active properties and probably are removed from culture water by a fractionator. Fractionator operating efficiencies are poorly defined and probably vary considerably from system to system. Experience in Maryland and Virginia suggests that foam fractionators improve water quality in recycled crab shedding systems. The extent of water quality improvement provided is currently poorly documented.

Biological Filters

Biological or nitrification filters are an important part of most aquatic culture systems. Their primary purpose is to convert toxic ammonia and nitrite to less toxic nitrate. Figure 7 shows the nitrogen cycle. The reactions shown around the circumference of the circle require oxygen and, except for the portion showing assimilation by plants, all the reactions occur in biological filters. The reactions inside the circle, denitrification, is an anaerobic process and occurs in filters only when oxygen is absent.

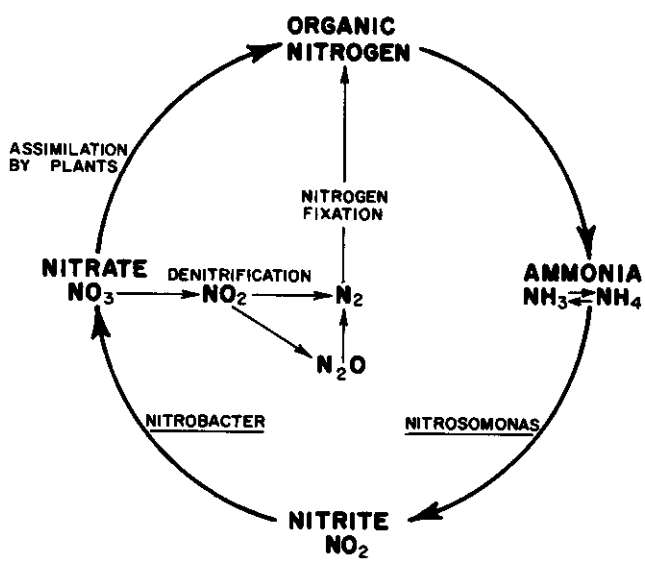

Figure 7. Nitrogen cycle.

Typical NH_3-N toxicity levels for fish culture is in the 0.5 to 1.0 mg/ℓ range with even lower concentrations causing problems for sensitive species such as trout. Nitrite is somewhat less toxic than ammonia for most fish although levels of less than 1.0 mg/ℓ can be lethal to sensitive species. Less sensitive species, such as catfish, can tolerate levels up to about 7 mg/ℓ of nitrite nitrogen. Even sensitive fish can tolerate 1,000 mg/ℓ or greater of NO_3-N (Colt et al. 1979).

Blue crabs are somewhat different. It appears crabs are more sensitive to NO_2-N than to NH_3-N. Current data indicate blue crabs can tolerate NH_3 concentrations up to about 1 mg/ℓ and NO_2 concentrations up to between 0.5 and 1.0 mg/ℓ (Lakshmi et al. 1984).

Problems have been encountered with biofilters so the emphasis here will be on possible solutions. Biological filters are living systems (i.e., bacteria) attached in most cases to fixed films (i.e., solid media) of some type. Because these filters are biological systems, they cannot react instantaneously to rapid changes in the ammonia or nitrite load placed on them. Rapidly increasing the load in a crab shedding tank increases the load on the biological filter. Because the filter does not react instantaneously, the ammonia level, and somewhat later the nitrite level, increases. Too great an increase in either of these levels can cause crab mortality.

Understanding the implications of the varying load problem depends somewhat on the type of biological filter used. There are several common filter types used including upflow and downflow submerged filters, trickling filters, the biodisk, and the biodrum. Figure 8 shows the basic design of a submerged filter. The water level in a submerged filter is maintained at a level above the filter media. All oxygen available to a submerged filter must be supplied from the water.

A trickling filter looks like a submerged filter except the water level is maintained below the media. A surface spray keeps the media wet as it trickles downward over the media. Large diameter media are used in trickling filters to assure that open passages are available throughout the filter. Thus, air movement through the filter is the major source of oxygen in trickling filters.

Figure 9 graphically describes the biodisk; Figure 10 shows the biodrum. The biodisk consists of a series of circular plates attached to a single shaft. The plates are separated from each other sufficiently that a bacterial film can grow on all surfaces of the plates. The plates are submerged, usually to about 40% of their diameter, in the liquid. The water is pumped axially (relative to the biodisk) through the tank. As the disks rotate, bacteria on the disks are alternately dipped into the liquid and exposed to air. Rotational speed is varied depending on the design but is sufficient to ensure that the bacteria are kept wet at all times. Oxygen for the bacteria is drawn primarily from the air.

The biodrum (Figure 10) operates very much like the biodisk except the water flows at right angles to the drum axis. The drum circumference is covered with a porous material and filter media, usually small plastic pieces of some type, are used to fill the drum. Bateria grow on the filter media surface. Oxygen for the bacteria is drawn largely from the air.

Available data have shown that oxygen avilability is critical to maintaining a high nitrification rate in biological filters (Wheaton 1977, Malone 1984). Although it is difficult to compare filter-operation efficiencies across various research projects and there are many conflicting results, it appears that the biodrum and biodisk provide somewhat higher nitrification rates than do submerged filters. Results by Manthe et al. (1984) indicate that submerged filter nitrification rates are often limited by oxygen even when it appears adequate oxygen is being supplied. Their results would suggest that the apparent edge in nitrification rate experienced using biodrum and biodisk systems may be due

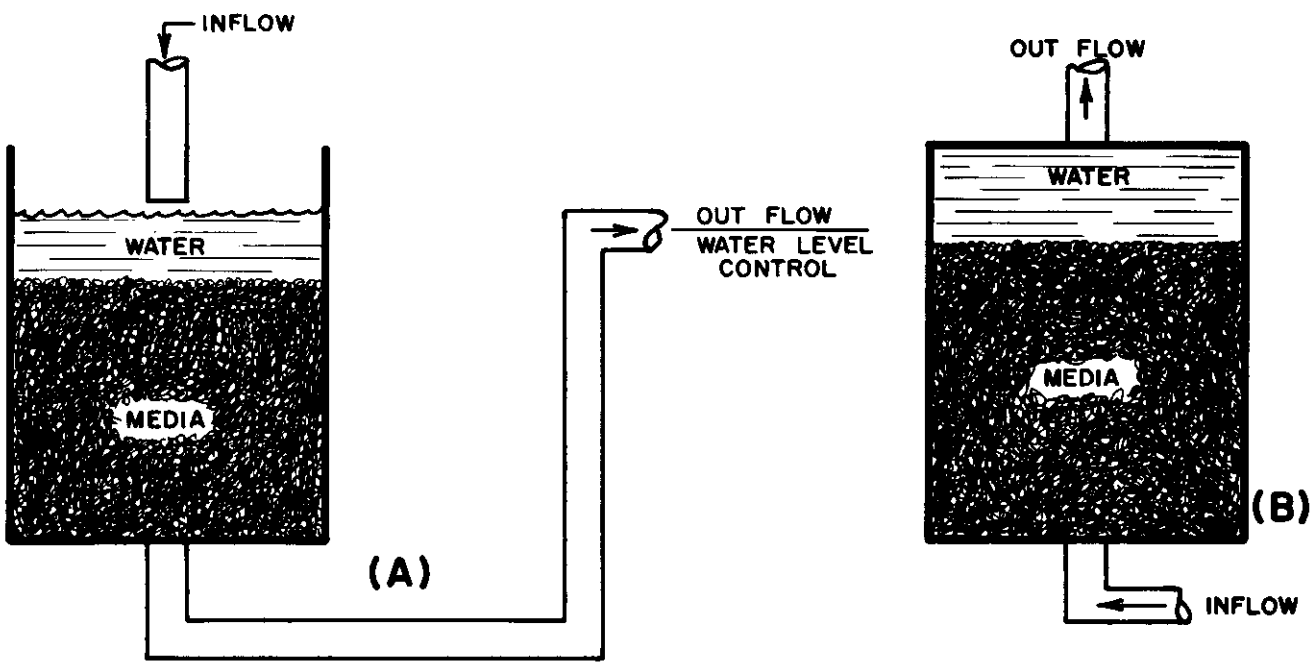

Figure 8. Basic design of a submerged biological filter. (A) Downflow filter. (B) Upflow filter.

to greater oxygen availability. Definitive results to confirm or refute this hypothesis are currently lacking.

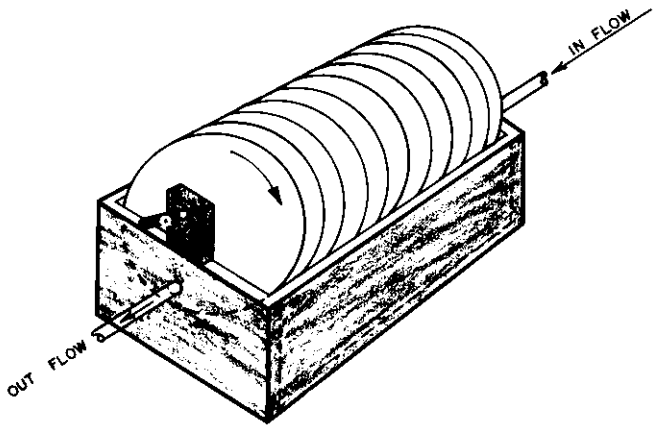

Figure 9. Diagram of a biodisk.

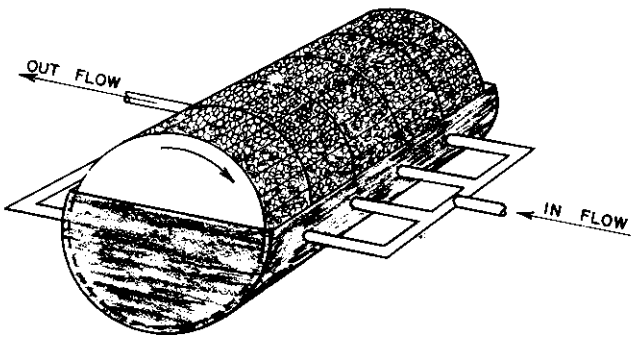

Figure 10. Diagram of a biodrum.

Bacteria can only metabolize a limited amount of ammonia or nitrite per organism. Thus, when the load on a filter increases, more bacteria must grow before more ammonia or nitrite can be oxidized. The oxidation rate will thus lag behind the change in load. If adequate filter surface area is available, higher bacteria populations and greater ammonia or nitrite oxidation can be achieved with the same filter. If all space on a filter is occupied by nitrifying bacteria before the ammonia load is increased, the filter has reached its maximum ammonia oxidation rate. The increased load will not be assimilated by such a filter. If excess space exists on the filter, the nitrifier population will increase as the load increases provided the increased load is maintained. The ammonia oxidation rate increase will, however, lag the increase in ammonia load. Biological filters can tolerate and will handle slowly increasing loads but will not handle rapidly increasing loads. Filters with essentially unlimited oxygen supply, such as biodrums, biodisks and trickling filters, will tend to respond better to increased loading than will submerged filters. Submerged filters will obviously respond to increased loads, but they have an additional limitation (i.e., oxygen) that biodrums, biodisks and trickling filters do not have.

Filters, like any biological system, are subject to Liebigs' law of the minimum. This law essentially states that a biological activity will occur only as rapidly as the least available element required will allow. Thus, if oxygen is in limited supply, it will determine the rate of ammonia oxidation. If another nutrient element required by the bacteria is unavailable in needed amounts, that will limit nitrification rate. The same is true for any other required element or condition whether it be temperature, iron or some other factor. Research is a continuous cyclic process of determining the filter-limiting factor and of finding a way of improving its availability so more rapid nitrification can be achieved. Once the more rapid rate is achieved another element may become limiting. Research is then conducted to identify and eliminate this new limit. The cycle continues until it becomes uneconomical or some limit cannot be removed.

It is known that the conversion of ammonia to nitrite is carried out by bacteria of the genus *nitrosomonas* (and other bacteria), while the conversion of nitrite to nitrate is carried out primarily by bacteria of the genus *nitrobacter.* It is also known that the optimal environmental conditions for bacteria from these two genera are slightly different. Thus, one method for improving the nitrification rate is to divide the biological filter into two parts that operate in series. The first part is operated at optimal conditions for *nitrosomonas,* which will convert the ammonia to nitrite. The second filter section is operated at optimal conditions for *nitrobacter* growth. This section will convert nitrite to nitrate. Various investigators have attempted to increase nitrification rate by dividing the filter. Some increase in nitrification rate is usually achieved, but the increased capital and operating costs usually more than offset the gains made.

Biological filters can also operate as a BOD removal device. In fact, trickling filters are more widely used for BOD removal from municipal wastewater than for aquaculture. Bacteria that remove BOD (hetrotrophs) grow faster than the autotrophic nitrifiers. Hence, in filters operating on water having a high BOD there is a competition for filter surface space between the autotrophic nitrifiers and the hetrotrophic bacteria. Several authors have stated that the presence of significant hetrotrophic bacteria in biological filters reduces the nitrification rate in the filter. Lomax (1976) attempted to demonstrate this principle in upflow submerged biological filters operating on closed cycle catfish culture systems. He was unable to demonstrate a statistically significant change in nitrification rate in a biological filter operating with different solids loading levels.

Injection of liquid oxygen into submerged biological filters may be another possible method for increasing oxygen availability to the bacteria. Whether this will increase nitrification and/or be economically viable depends on the system used.

GAS CONCENTRATION CONTROL

Gas concentration control in aquatic culture systems generally refers to oxygen or carbon dioxide levels. However, under some conditions (e.g., supersaturation) nitrogen can cause gas bubble disease. Gas concentration control generally requires the addition of oxygen and the reduction of carbon dioxide.

Oxygenation can be done in many ways but essentially all methods require that air or pure oxygen be brought into intimate contact with the water. The surface-to-volume ratio of the water must be greatly increased to get rapid oxygen exchange. Thus, aerators generally break the water into droplets and attempt to surround each droplet with gas or they attempt to make many small bubbles of air in the water. Both these systems increase the air-water surface area and increase oxygen transfer rate.

Aeration in culture systems is usually aimed toward supplying oxygen for the cultured organisms. What is often forgotten is the oxygen consumption by bacteria in the filter and throughout the system. Often the biofilter bacteria will use as much or more oxygen than will the cultured organisms. This oxygen must be supplied, usually by aeration. In crab-shedding systems, oxygen demand is due to decomposition of crab wastes in the water and the metabolic demand of the crabs. Crabs are stressed during molting so metabolic demands are unusually high. Because feeding of molting crabs is unnecessary, the oxygen demand due to the addition of feed does not exist. However, in crab culture systems the feed may be a significant oxygen demand, particularly if overfeeding occurs.

Oxygen must be available throughout the system. Holding tanks must have uniform oxygen distribution or crabs will crowd into the high oxygen areas. This can lead to cannibalism and decreased utilization of tank space. Inadequate oxygen distribution in biofilters produces anaerobic spots in the filter, the generation of noxious gases such as hydrogen sulfide, and decreased filter performance.

System design, which provides uniform circulation through all parts of the culture tanks and filters, is the best defense against oxygen depletion. Adequate built-in aeration equipment and plans for insertion of emergency aeration equipment are initial design considerations.

ION BALANCE

Salt or brackish water contains many ions. Little research work has been done on what happens to the ion balance in recirculating systems. There are indications that calcium concentrations change significantly due either to absorption by the crabs as they build shell material or from buffering the acids produced in the culture systems. Other ion concentrations probably also change. For example, certain feeds may breakdown and release chlorides. Nitrate concentrations often increase with time.

In the past, ion concentrations were not monitored because the laboratory procedures to do so were difficult, time consuming and costly. Where 10% make-up water is added during each pass through the system, ion concentrations changed but not enough to affect the cultured animals. As the percent of water recycled increases this may no longer be true. Ion concentration monitoring may become necessary and chemical additions to correct deficiencies may have to be added. Using calcium carbonate-based rock for biofilter media has long been used to control pH and to supply calcium ions in culture systems. Other similar systems may be necessary in the future.

SUMMARY

Culture systems are typically comprised of subsystems including the culture tanks, the pumping and plumbing system, the filtration or water quality control system, the gas concentration control system and the feeding system. Each subsystem may be designed in a variety of ways depending on how the particular system will be used and managed.

REFERENCES CITED

Brett, J. R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus*. *J. Fish. Res. Board Can.* 9(6):265–323.

Colt, J., S. Mitchell, G. Tchobanoglous and A. Knight. 1979. The use and potential of aquatic species for wastewater treatment. Appendix B – The environmental requirements of fish. *Calif. State Water Resources Control Board Publ.* 65.

Dwivedy, R. C. 1973. Removal of dissolved organics through foam fractionation in closed cycle systems. Paper No. 73–561. Available from: Am. Soc. of Agricultural Engineers, St. Joseph, MI.

Lakshmi, G. J., C. M. Trigg, H. M. Perry and A. Venkataramiah. 1984. Effect of ammonia accumulation on blue crab shedding success. Final report Proj. R/RD2. Available from: Mississippi-Alabama Sea Grant Consortium, Ocean Springs, MS 39564.

Lawson, T. 1978. Venture design parameters for air injection into a foam fractionation system. College Park, MD: Agricultural Engineering Dept., Univ. of Maryland. Dissertation.

Lomax, K. 1976. Nitrification with waste pretreatment on a closed cycle catfish culture system. College Park, MD: Agricultural Engineering Dept., Univ. of Maryland. Dissertation.

Lush, J. 1976. Orifice aspirator as a foam fractionation air injection system: Design effects. College park, MD: Agricultural Engineering Dept., Univ. of Maryland. Thesis.

Manthe, D., R. Malone and S. Kumar. 1984. Quantitative evaluation of submerged biological filter designs in closed recirculating blue crab systems. Paper presented at the World Mariculture Society Meeting, Orlando, FL.

Wheaton, F. W. 1977. *Aquacultural Engineering.* New York, N.Y.: John Wiley and Sons.

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PROFITABILITY COMPONENTS OF CLOSED BLUE CRAB SHEDDING SYSTEMS IN THE GULF OF MEXICO

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INTRODUCTION

The production of soft-shelled blue crabs occurs from Chesapeake Bay through Texas. This extensive coastal region has diverse natural systems in which fisheries for hard-shelled blue crab exist. A popular aspect of the blue crab fisheries is their potential to yield high unit-value soft-shelled products. Maryland, Virginia, and Louisiana remain the top producers of soft-shelled blue crabs. A resurgence of business interest in this activity occurred in the early 1980s. Sea Grant-sponsored research and advisory efforts yielded successes to both lead existing businesses and stimulated new operations. Business, research, and advisory service interests have recognized the value in pursuing shedding procedure improvements to existing float, land-based flow-through and land-based closed systems. There is merit to assessing local conditions in terms of water quality, land availability, and peeler supply before choosing a method. Each shedding approach can be an appropriate financial choice in certain situations. Due to a lack of standardization and documentation of the floating pen and flow-through approaches, the following information reflects a conceptualization of the well-documented closed system being studied by researchers in the Gulf of Mexico area.

FACTORS CRITICAL TO CLOSED SYSTEM FINANCIAL SUCCESS

There are numerous factors of importance in the design and operation of a closed system for shedding blue crabs. The following are offered for careful consideration because of their role in determining profit levels. Additional factors which must be understood are contained in the various articles comprising the proceedings of the *National Symposium on the Soft-Shelled Blue Crab Fishery*.

Profitability of a closed system will be determined by at least five factors. A brief description of each factor follows.

1. ***System turns:*** This represents the number of times the system of crab vats can complete the shedding cycle during the season of peeler availability.
2. ***Survival:*** The survival of crabs in the system from the time of stocking until removal as a successfully shed crab.
3. ***Capacity utilization:*** The relationship between the owner's success in supplying peeler crabs to the system and system's capacity from an engineering viewpoint.
4. ***Market prices:*** A series of prices that vary by size of crab. The prices received can be reflective of direct marketing by the shedding system owner as opposed to selling through wholesalers.
5. ***System size:*** An indication of the need to plan a system suitable to the supply of peeler crabs and labor availability.

System Turns

Blue crab shedding businesses are subject to seasonal operating problems. The availability of peeler crabs varies by month with many months not yielding appreciable supplies. It is essential that the owner achieve the highest number of system turns during the operating period. The number of turns is primarily determined by the quality of peelers available. Quality here refers to the length of time between peeler capture and shedding. The peelers showing red-line sign reflect the best quality as shedding occurs within 1 or 3 days. Longer periods in the system are required for pink-line shedders. The green (white line) crabs may require 10 days on an average. As quality improves from the peeler suppliers, the system turns increase. The system builds a foundation for success when a high proportion of quality shedders comprises the supply.

Secure information on seasonal availability of peelers in your area of interest; then determine the likely proportion of peelers that fall into the red-, pink-, and white-line categories. This information identifies the number of potential turns during a season. Labor and overhead are used more efficiently when the number of system turns is high. Peelers that are close to shedding permit a higher number of turns and represent a higher value to the system owner. Thus, prices for peelers may be established to encourage peeler suppliers to deliver graded peelers much as the finished product is graded by the owner for maximum market price.

Survival

Input to the system is critical as described in the previous section. However, the owner must manage the system to obtain the highest possible survival of the peelers. The

percentage of peelers that survive to yield a salable soft-shelled product must be high. Management of the closed system can determine the effective cost of individual soft-shells sold. A survival rate of 50% will double the cost of peelers eventually sold. Buying two inputs (peelers) to produce one salable product (soft-shell) indicates poor management of the closed system. The owner also has fewer marketing options when the level of survival is low. High survival means lower costs resulting in more markets being available for products with lower breakeven prices.

Although not documented in reports at the time this paper was written, the owner of a closed system should realize that there must be a relationship between survival percentage and system turns. The further a peeler is away from becoming a soft-shell when placed in the system, the more likely it will cause mortality due to aggressiveness. Shedding areas built and managed to separate poor-quality peelers require materials, space and labor to perhaps offset the tendency for poor-quality peelers to impact both system turns and survival.

Capacity Utilization

For any closed shedding system developed, there will be a maximum capacity determined by biological and engineering factors. Once selected and constructed the overhead or fixed costs will be lower per dozen soft-shells produced when high rates of use occur. Certain other nonmaterial-type costs are also lowered per dozen when use of capacity increases. Labor and energy expenses will be more efficiently used in operating the system at high-capacity rates. Blue crab shedding systems often consist of several sets of vats holding peelers. Each set of vats can be used at lower unit costs when capacity utilization is high. In addition, the use of several sets of vats can spread fixed costs over more production. Lower per-unit-production costs result from both aspects as capacity use increases.

The size of a blue crab shedding system and its capacity utilization are determined by the owner's success in securing a consistent peeler supply.

Market Prices

Sales to wholesalers, restaurants and retail markets by the closed system owner are by the dozen. In analyzing the prospect for a feasible business the direct marketing of soft-shells can mean higher average prices than appear in market news reports. Production from Virginia and Maryland dominate the market for fresh soft-shells beginning in June each year. Gulf states experience good production in April and May. Soft-shells from the Gulf reach the market in fresh form before the Chesapeake producers. Frozen soft-shells are available throughout the year. Some opportunity awaits the Gulf shedder to enter the market with a fresh or recently frozen crab two months before the peak supply from Chesapeake Bay. Gulf shedders will eventually have to face market competition in mid-summer when production peaks elsewhere.

A knowledge of the method of assigning grades to system production can assist in market-pricing decisions. Shedders in the Gulf frequently use fewer grades to classify their shed crabs than do producers on the east coast. A price advantage over quoted east coast prices may result from an owner's skill in reaching the market earlier, offering fresh and frozen products, having larger average soft crabs, and grading to suit local markets. The establishment of consistent grades recognized nationally eventually must come to the industry as growth accelerates. There are substantial variations between local and national markets. Enough price variation exists to make this an area that can yield payoffs to the owner with insight to the market opportunities. Use of published prices for east coast soft crabs could be used as minimum prices to estimate profitability of Gulf shedding operations.

Soft crab market grades used for east coast suppliers include:

Medium	3.5 to 4.0 in.
Hotel	4.0 to 4.5 in.
Prime	4.5 to 5.0 in.
Jumbo	5.0 to 5.5 in.
Whale	5.5 and larger

The matter of grades within a Gulf state can vary. An example is the region's major producer—Louisiana. Within the state soft-shelled crabs are graded by any of three methods:

1. the previously cited east coast or Chesapeake method;
2. a three-grade method based on small, 2 to 4 oz per crab; medium, 4 to 6.5 oz per crab; and large, >6.5 oz; and
3. a series of grades based on a "counter" soft-shell with all other sizes graded in reference to the "counter" (e.g., 2:1, 3:1, 4:1).

A profitable operation can be achieved or improved by pre-investment consideration of local market prices. There is opportunity and, therefore, incentive to achieve prices above the widely quoted east coast prices.

System Size

Closed systems in the Gulf are a relatively new business opportunity. Experience with a wide range of system sizes consequently has not occurred. All businesses have the characteristic that some efficiencies can be realized from an increased scale of operation—up to a point. An individual interested in establishing a shedding business must plan a scale of operation that (1) matches well with the likely peeler supply, (2) utilizes **existing** building and equipment to the maximum, and (3) does not exceed labor availability, especially if the labor is contributed by family members.

PRO FORMA CLOSED SYSTEM BUDGET

The recent development of closed system shedding

techniques restricts the amount of economic information available. Planning by people intending to build systems must, therefore, include the use of many assumptions. The previously outlined material will assist people with decisions as to the key factors. The following information will demonstrate the relationships among factors when various assumptions are made. The information, assumptions in most cases, represents educated estimates contributed by scientists and shedders developing the systems. All estimates are represented as ranges. In this way interrelationships will be evident if an individual determines that an estimate used initially was unsuitable.

A pro forma budget is a projection of costs and revenues that could be experienced in a business endeavor. Any shedding budget must be based on an estimate of the time period when peelers are available. It is also essential to allocate the total supply throughout the period to sensitize owners to the importance of proper management at times key to year-end profitability.

The assumed operating period in the Gulf is April through October (by month: April 25%, May 12.5%, June 12.5%, July 12.5%, August 18.8%, September 12.5% and October 6.2%). A total of 214 calendar days occurs during that period. Three average lengths of stay in the system for peelers were assumed for illustrative purposes: 3, 5, and 7 days. The maximum number of system turns can then be calculated by dividing the average system stay into available shedding days. The three levels of system turns are 71 (high), 43 (medium), and 31 (low).

The system portrayed in this section consisted of two units of three shedding vats per unit. There were two filters, one water storage tank, and two 1.33-hp electrical motors driving the pumps. A description of closed systems is available in other sections of this proceeding. A fully enclosed building, 19 X 14 ft, on a slab houses the operation.

The suggested point to initiate the process is the use of 200 crabs per vat maximum capacity. Other factors such as system turns, survival rate, and capacity utilization can then be used to adjust productivity for use in the pro forma budget. The entries in Table 1 depict the numerous yields that a shedder could experience. Sales and profitability prospects are obviously quite variable as a result. An owner will also experience variation in capacity utilization and survival rates throughout the season.

The three sections of Table 1 relate to the three levels of system turns designated as low (31 turns or 7 days per turn), medium (43 turns or 5 days per turn), and high (71 turns or 3 days per turn). Because supply of peelers is a well-known constraint faced by shedding system owners, the medium- or low-turn sections should be used by those planning new operations. The crab-supply factor also comes into the decision process as the percentage of capacity that can be utilized. A new operator may face no better than a 50% average capacity utilization rate initially. Survival rates should increase with experience but may be affected by efforts of the owner to operate at a higher level of utilization.

TABLE 1.

The number of soft-shell blue crabs produced from a 1200-crab-capacity-per-turn closed system for various numbers of turns, capacity utilization levels, and survival rates.

	Capacity Use Level (%)		
Survival (%)	50	70	90
	Low level of turns, 31		
65	12,090	16,926	21,762
75	13,950	19,530	25,110
90	16,740	23,436	30,132
	Medium level of turns, 43		
65	16,770	23,478	30,186
75	19,350	27,090	34,830
90	23,220	32,508	41,796
	High level of turns, 71		
65	27,690	38,766	49,842
75	31,950	44,730	57,510
90	38,340	53,676	69,012

The pro forma budget presented in Table 2 reflects the medium level of turns in a system operating at 50% capacity with 75% survival. The 19,350 shed blue crabs represent 1,613 doz. A gross revenue estimate was derived by dividing the production into April–June and July–October periods. This was done to reflect a different size distribution of shed crabs during the season. Fewer soft-shells reach the large category during the second period. Thus, the second period includes a higher percentage of medium-size soft-shells with there being no change proposed in the small category between periods (small, 2 to 4 oz per crab; medium, 4 to 6.5 oz per crab; large, $>$ 6.5 oz per crab).

TABLE 2.

Annual pro forma income statement for a closed blue crab shedding system, 1984.*

Revenue		
1,613 doz crabs at $17.75/doz		$28,631.00
Costs		
labor (1,720 hrs at $5.00/hr.)	$ 8,600.00	
peelers (25,800 crabs at $0.30 each)	7,740.00	
fuel (peeler collection, marketing)	1,365.00	
building debt reduction	1,092.00	
utilities	450.00	
system debt reduction	390.00	
miscellaneous (supplies, freezers)	320.00	
Total	$19,957.00	
Net Revenue		$ 8,674.00

The average-weighted price used per dozen was calculated from mid-1984 wholesale quotes. By factoring in the effects of price variation throughout the season, then assuming a size distribution for the Gulf and proposing that the system owner could be able to secure the wholesale price for his relatively small production, the average price of $17.15 per dozen was estimated. Total revenue of $28,631.00 must be considered the highest possible for an owner during the early years of operation. Securing enough peelers to keep the system operating at 50% capacity throughout the year will be a major problem. Recall that Louisiana differs from the Chesapeake Bay area in that a fishery specifically for peelers exists in only a small area of the state.

Owners living outside the Lake Pontchartrain and Lafitte-Barataria areas must rely on indirect methods to acquire peelers such as purchase from crabbers. Operation at 50% capacity for the April through October period will be an achievement. Also important in the gross revenue calculation is the use of wholsale prices as the price received. The use of prices reflecting the owner selling to wholesalers would lower the total revenue estimate. An alternate total revenue estimate reflecting the use of $13.33 per dozen results in $21,501.00 compared to the $28,631.00 estimate of Table 2. Net revenue decreases to $1,544.00. The value of pre-investment planning to secure a reliable peeler supply and wholesale prices should be evident.

The labor entry in Table 2 reflects the significant time devoted to the shedding operation. In many cases the interest is in family-operated shedding businesses. Uncompensated family labor can be a major contribution to success. Regardless of whether or not uncompensated labor is present, the entry conveys the message that a large amount of time to manage the facility will be necessary. The payout on the building to house the system occurs over 5 years. A cinder-block structure, 19 X 14 ft, on a reinforced 6-in. concrete slab houses the shedding system. This area would permit the addition of another unit of three vats without a building expansion. Recapturing the investment in building the shedding system also occurs over 5 years. The system cost is a small annual cost to recapture. This is a factor that stimulates people to become commercial crab shedders. The other costs and marketing factors identified previously indicate the importance of a thorough consideration of all aspects before establishing a blue crab shedding business.

CONCLUSIONS

Soft-shelled blue crabs are a highly valued seafood item. The development of successful shedding technology within the management and investment capabilities of many people has encouraged expansion in the industry. In general terms, the soft-shelled blue crab closed systems have many attractive business attributes:

1. Owners are managing animals by number through direct observation. Problems with other aquaculture systems often arise because the number of animals in a pond may be variable. The quantity and poundage of animals are uncertain and management must occur in this situation with animals hidden below the water surface.
2. There is no cost for feeding the peelers. Feed costs can be a significant part of aquaculture operations.
3. The short length of time that blue crabs are in the system keeps disease problems to a minimum.
4. The small-scale closed systems are within the investment abilities of more people than are large, pond-type aquaculture operations.
5. A good market exists from the standpoint of both local sales and opportunities for direct marketing.

These attributes will stimulate expansion as individuals become more knowledgable. There can be no substitute for a thorough analysis of local peeler-procurement procedures and direct sales to restaurant and retail users. Securing the higher wholesale price can be essential to success. In periods of peeler scarcity, it is possible to increase the price paid for peelers and still maintain a profitable margin.

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THE DEVELOPMENT OF AN EXPORT MARKET FOR SOFT CRABS: JAPAN

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INTRODUCTION

During 1984, several samples and larger shipments of soft-shelled blue crabs were sent to Japan. As a result, several questions were generated as to the use, acceptance and potential of soft crabs as an export item to Japan. To help answer those questions, visits to Japanese importers and distributors in Tokyo, Osaka, Nagoya and Yokkaichi City were conducted by Dr. William DuPaul of the Virginia Institute of Marine Science, Mr. Peter Law, of the Virginia Department of Agriculture and Consumer Services, and Mr. Terry Conway of Handy Soft Crabs. Additional support for this project was provided by the Gulf and South Atlantic Fisheries Development Foundation.

The purpose of the trip was to visit companies which had previously imported soft crabs, tested samples or had expressed an interest in the product and to gather information that would better help us to understand the export market potential for soft crabs.

Soft-shelled crabs are a new product to Japan which has generated much interest in the seafood-marketing business. The excitement over the potential for a new product for export, however, is tempered by the complexity of the Japanese market and the difficulties in developing a favorable long-term market and reputation. A similar situation has developed in Hong Kong. Soft-shelled crabs have attracted much favorable attention as the result of samples shipped to several Hong Kong export/import companies.

Most Japanese businessmen, familiar with the product, think that soft crabs have a place in the market. To what extent and size are uncertain, but all agree that it will have to be done carefully if it is to be successful. Consistency in supply, cost and quality will be important factors in the development of an export market.

Approximately 30,000 doz soft crabs have been shipped to Japan and current inventories remain high. A reasonable estimate of present use is about 30,000 doz per year. It is not unreasonable to estimate that sales in two to three years could reach 60,000 doz per year.

THE JAPANESE MARKET

Price Structure and Market Position

Current inventories of soft crabs in Japan were purchased at approximately $5.50/lb ($11.10/doz primes) CIF (shipping term which means the seller quotes the price that includes cost, insurance, and freight to the point of destination). An additional 20% should be included for handling, duty and miscellaneous expenses. Most of the current inventory in Japan consists of "primes." The concensus of importers and distributors indicated that primes or a size smaller would be most amendable to the Japanese market as it now stands. The size preference is related to the "high" cost per piece or per crab as any size larger than primes would add to their concern.

Most people familiar with soft crabs felt that the best market would be in Japanese mid- to high-class restaurants and in several of the seafood-chain restaurants that specialize in particular items or cater to a more affluent clientele. It was not anticipated that soft crabs would be suitable for retail markets and fast-food eating establishments.

Market Channels

One of the factors involved in the relatively high cost of soft crabs at the restaurant level may be the multi-layered distribution chain predominant in Japan. In one case, there were four layers (or transactions) involved to get the product at the restaurant level. These transactions all added to the final cost of the product which may have been the cause for concern of the cost of the product.

Brand Identification

Several Japanese importers and distributors liked the idea of brand development and identification. However, if a brand name is established, some provision would have to be made to provide exclusive rights to a particular brand. Both importers and distributors were concerned over the potential for a "price war" involving the same brand of soft crabs imported by more than one company.

Quality

There were no problems or doubts relative to the quality of soft crabs and several favorable comments were made about the fact that the crabs were individually quick frozen (IQF) and individually wrapped. Although IQF soft crabs is not a standard industry practice, it should not present a problem as long as the product is well cared for during packaging and shipping. From a physical point of view, several negative comments were made about the fact that

some crabs had only one claw and some of their legs were missing. Generally, packers and processors only guarantee one claw and "most of their legs." At some point in time, when the market becomes better developed and more sophisticated, there may be a demand for premium crabs with both claws and all their legs.

Preparation

Several methods of preparing soft crabs were observed during the trip to Japan. When crabs were heavily marinated with a soy-and-mustard sauce, the flavors of the crabs were lost. In one case, the crabs were deep fried and served with a very spicy sauce which did not lend itself to the preparation. In the same restaurant, the crabs were fried in a very thick pancake-type batter which overpowered the taste and appearance of the soft crab.

More acceptable preparations of soft crabs were sampled during the course of a traditional Japanese meal. The crabs were lightly marinated, deep fried without a batter or coating and served on a large platter. The diners then dipped sections or the whole crab into a variety of light soy-sauce preparations. This method of preparation appeared to be most agreeable to both the American and Japanese diners at the table.

Other methods of preparation included a tempura-style dish and a dish in which the soft crabs were rolled in a ball, coated in a light batter, then deep fried and served with a variety of sauces. Both preparations were good and acceptable.

There may be a technical problem with deep-frying soft crabs. Several comments were made to the effect that soft crabs "ruined" the oil in which they were fried. The high-moisture content of soft crabs may be the cause of the problem. In one case, soft crabs were deep fried in soy bean oil at 188°C. Additional inquiries to this problem will have to be made.

It became obvious that the distributors or importers of soft crabs will have to undertake an educational and promotional campaign to properly introduce soft crabs to the Japanese market. Because soft crabs are a totally new item, they have generated quite a lot of interest but, at the same time, unfamiliarity with the product will require more deliberate promotional strategy to ensure a long-term success.

Promotion and Advertising

One larger distributor to restaurants has taken an advertisement for soft crabs in a nationally distributed magazine "Gourmet Cooking (Senmon Ryori)." Figure 1 is a reproduction of the advertisement. The advertisement promotes soft crabs as the new delicacy from the east coast of the United States and that they can be prepared in a variety of ways acceptable to the Japanese palate. In addition, the same company has sponsored a radio advertisement expounding the virtues and availability of soft crabs.

A major restaurant chain specializing in seafood has included soft crabs on their menu in seven of their restaurants. The restaurants are advertised nationally on all major TV networks and feature soft crabs on both the lunch and dinner menus. The set-lunch features soft crabs, roast beef and giant scallops priced at 4200 yen excluding tax. Figures 2 and 3 are reproductions of this menu.

最高級シー・フーズ・メニュー

Soft Crabs

ソフト・クラブ

ソフト・クラブとは、甲羅から爪まで柔らかいため、丸ごと食べることの出来る蟹のことです。
この『ソフト・クラブ』は、アメリカ東部海岸産ブルー・シー・クラブ(渡り蟹の一種)の
脱皮した直後のことを言い、
そのため甲羅・爪・脚など本来堅くて食べることの出来ない所が、極めて柔らかくなっている訳です。
なお、今回輸入いたしました商品は、そのまま調理していただける様、
目、えらなど食べることの出来ない処を取り除き、急速冷凍をかけ、
一匹づつラップに包んであります。
ソフト・クラブは、アメリカのレストランにおいては最高級のシー・フーズ・メニューになっており、
フライ、グリル、またサンドウィッチ素材として調理されておりますが、
天ぷら・からあげ等、和食・中華料理にも広くご利用いただけるものと思います。

HOTEL SIZE	PRIME SIZE	JUMBO SIZE
ホテルサイズ	プライムサイズ	ジャンボサイズ
平均一匹当り約57g	平均一匹当り約74g	平均一匹当り約100g
(甲羅の長さ:10~11.5cm)	(甲羅の長さ:11.5~12.5cm)	(甲羅の長さ:12.5~14cm)
48匹(内箱入)×10入/ケース	36匹(内箱入)×10入/ケース	24匹(内箱入)×10入/ケース

*この蟹は、成長する約3年間のあいだに23回も脱皮を繰り返すため、各種のサイズが有りますが、利用しやすい3サイズを輸入しました。

代理店

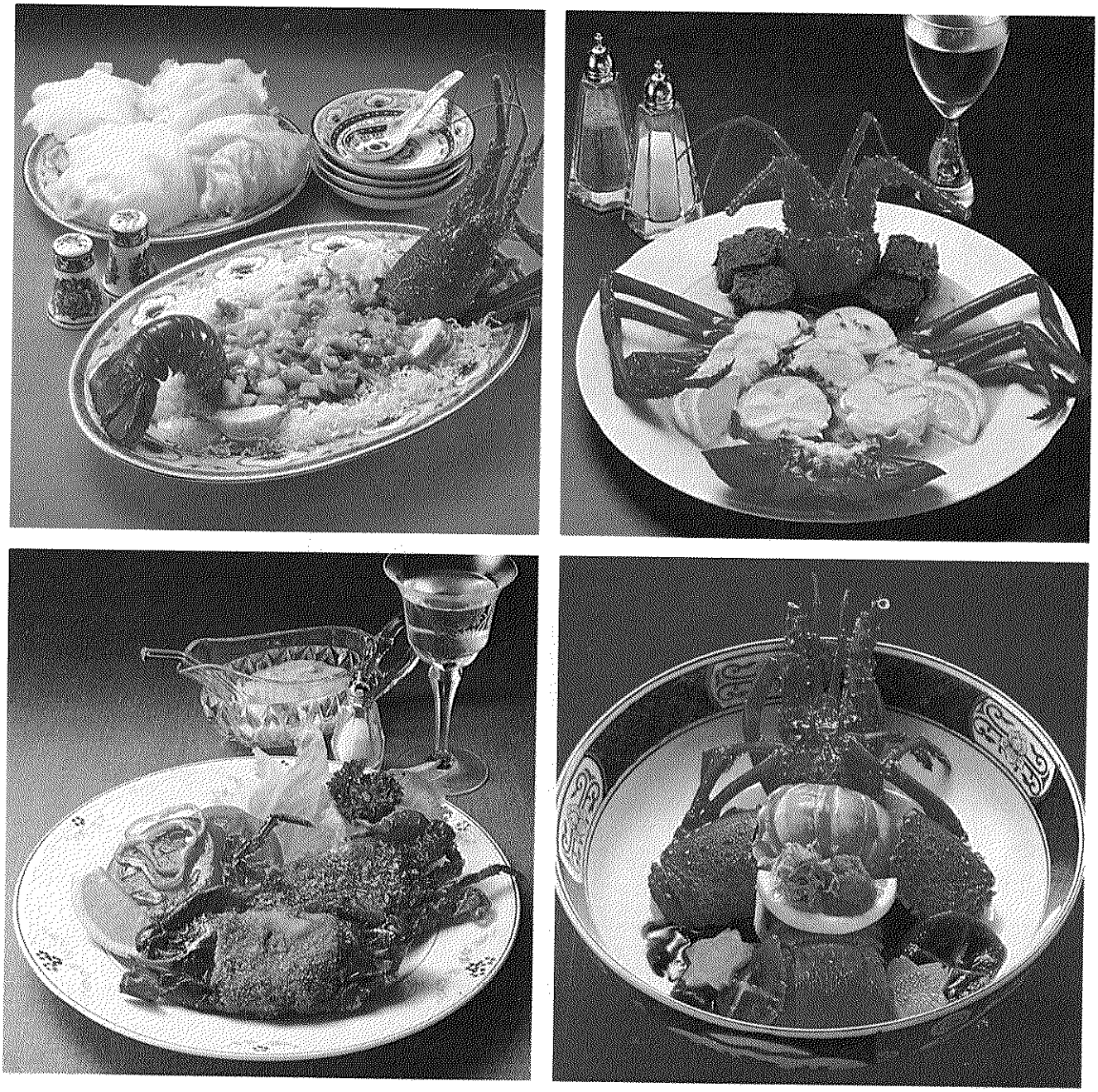
輸入元

フシタツ商事株式会社

名古屋市中村区名駅南一丁目15-10

TEL〈052〉582-4711(代)

Figure 1. Reproduction of an advertisement for soft crabs in a nationally distributed magazine "Senmon Ryori."



中納言コレクション。

味は見るよりも、聞くよりも、食べるもの。
まずは一度中納言の白いテーブルクロスの前にまわって、
中納言・味のコレクションをご賞味ください。

Figure 2. Reproduction of menu from a major restaurant chain which includes soft crabs depicted in lower left-hand corner.

活伊勢海老
ランチタイムメニュー

活伊勢海老を使った
昼食用サービスメニュー。

お昼のサービス品(A)
¥3,500
・伊勢海老のマヨネーズサラダ
・伊勢海老のクリームコロッケ
・伊勢海老の甲羅揚げ
・伊勢海老の合わせみそ汁
・コーヒー

お昼のサービス品(B)
¥4,200
・オードブルサラダ
・伊勢海老の活造り
・伊勢海老の甲羅揚げ
・伊勢海老の焼物
・伊勢海老のコロッケ
・伊勢海老の合わせみそ汁
・お茶漬け

スペシャル・ランチ
¥4,200
・スープ
・サラダ
・ソフトクラブのフライ
・貝柱のバター焼
・ローストビーフ
・ライス
・お漬け物
・デザート

Figure 3. Reproduction of menu from major restaurant chain featuring on its set-lunch menu soft crabs, roast beef and giant scallops priced at 4200 yen excluding tax.

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985, 77–79.

MICROBIAL AND NUTRITIONAL ATTRIBUTES OF SOFT CRABS

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INTRODUCTION

Soft-shelled blue crabs (postmolt hard blue crab, *Callinectes sapidus* Rathbun) continue to be sought as a special, high priced culinary delight. Based on current costs per pound (≥ $8.00/lb. retail), the soft crab remains one of the highest priced seafood selections. Although consumption figures are not available, recent increases in domestic production and prices suggest consumer demand continues to exceed supply. In Florida alone, there was essentially no production prior to 1978; whereas, the 1983 production was in excess of 50,000 pounds with a dockside value above $70,000 (Andree 1985). In light of these developments more information is needed regarding the handling and storing of the product, and to explain their relative dietary contribution. Common retail practice is to store prewrapped soft crabs either frozen (0°F; −18°C) or fresh (40°F; 4.2°C). Based on commercial experience, the frozen shelf-life for properly packaged soft crabs can exceed 12 months. However, there are no reports on the recommended refrigerated shelflife. Likewise, there is no formal published data on the nutritional constituents of soft crabs. This report addresses these issues.

METHODS

Soft crabs were obtained from a commercial shedding facility in Cedar Key, Florida. This operation used common procedures for holding premolt hard blue crabs in flow-through water systems. The water used was drawn from the adjacent brackish waters which have been monitored to meet water quality standards sufficient for harvest of shellfish (FL Dept. of Natural Resources, Dept. Rules, Chapter 16B–28; median fecal coliform Most Probable Number (MPS) of water shall not exceed 14/100 mℓ and not more than 10% of the samples shall exceed 43/100 mℓ). Crab samples were taken during spring (May) and fall (October).

The postmolt samples were immediately wrapped in plastic film and held on ice prior to initiating analyses. Microbial analyses began within 24 hours (0 day) after shedding. Nutritional analyses were performed on spring samples prefrozen on zero (0) day. All analyses used the entire edible portion (whole crab dressed or cleaned with gills, apron, eyes and mouth parts removed). The crabs were cleaned just prior to analyses.

Microbial analyses included aerobic plate counts (APC) with incubation at 25°C. Fecal coliforms and *Vibrio parahaemolyticus* were tested by methods outlined in the U.S. Food and Drug Administration's *Bacteriological Analytical Manual* (USFDA 1978). All analyses were conducted in duplicate per sampling day (0, 2, 4, 6 and 8 days storage).

Nutritional analyses included proximate composition (AOAC 1980), minerals (Na, K, Ca, P, Mg, Zn, Fe, Cu, Mn, Cd, and Hg) and fatty acids. Gall et al. (1983) should be referenced for more specific methodology. Mineral analyses employed an atomic absorption spectrophotometer (Perkens-Elmer Corp., Models PE503 and 5000). Ashed samples were dissolved in a final concentration of 0.2 N hydrochloric acid. Phosphorus was assayed colorimetrically using tartrate-molybdate-ascorbic acid reagent, and mercury was determined by the Perkens-Elmer Mercury Analysis System.

Fatty acids were determined by methyl ester preparations (McCreary et al. 1978) separated by gas-liquid chromatography (Hewlett Packard Model 5840-A gas chromatograph) equipped with a Hewlett Packard Model 7671-A automatic sampler and 6-ft, 4-mm i.d. columns packed with 10% Silar 10 C – Applied Science Labs. Acids were identified by comparison with retention times for pure fatty acid methyl ester references (Nu Chek Prep, Inc.).

RESULTS AND DISCUSSION

High microbial counts coupled with adverse product evaluations indicate soft crabs have a relatively short refrigerated shelflife (Table 1). After 6 days storage below 35°F (1.7°C) or on ice, the average microorganisms per gram (APC, 25°C) ranged from 0.2 to 1.2 × 10^8. The crabs had become flaccid, exuding excess weepage with obvious slime and objectionable odors. The raw product was judged unacceptable on the sixth day of refrigeration. This result is expected realizing the vulnerable nature of the initial crab tissues infilterated with a high moisture content resulting from the natural, untreated water supply and no subsequent washing. Attempts to treat the water supply to better facilitate crab survival and lower initial microbial counts would not necessarily assure an extended shelflife. The soft, moist condition of the crab tissues is apparently a suitable media for prolific bacterial growth. The low counts for fecal coliforms is a favorable reflection of the

water quality and attests to the use of water monitoring by standard conditions.

TABLE 1.

Aerobic plate counts (APC, 25°C – microorganisms [g]), fecal coliforms (FC – MPN/g) and *Vibrio parahaemolyticus* (VP – positive samples/3 samples tested) for whole, raw soft crabs stored on ice in refrigeration (35°F, 1.7°C).

Storage (days)	Spring (May)			Fall (Oct)		
	APC	FC	VP	APC	FC	VP
0	2.5×10^6	<2	3/3	2.0×10^5	<2	2/3
2	9.7×10^6	<2	2/3			
4	4.6×10^7	<2	0/3	1.4×10^6	<2	
6	1.2×10^8	<2	2/3	2.2×10^7	<2	
8	2.3×10^8	<2	0/3			

The detection in crabs of the potential pathogen, *Vibrio parahaemolyticus*, is common for seafoods from similar areas and should not pose a health threat unless careless handling affords a chance for cross-contamination with cooked or ready-to-eat items. Retailers should be warned of the consequences and exercise care in handling and storage, i.e., do not store raw soft crabs near or with cooked crabs or with other ready-to-eat seafoods, and never reuse soft crab packaging or containers to hold cooked items. Note that *V. parahaemolyticus* did decrease during refrigerated storage.

The high moisture content contributing to the bacterial growth was evident in the proximate analyses (Table 2). Typically, raw blue crab meat has a moisture and protein content of approximately 80% and 16%, respectively (Sidwell 1981). The protein content in immediately post-molt blue crabs is lower due to the lower proportion of muscle tissues. The protein loss is balanced by an increase in water content, which is actively taken in to expand the new molt. There is also more ash content resulting from the higher proportion of tissue destined to be shell. Notice that lipids are not significantly different.

TABLE 2.

Proximate composition (%) for whole, raw blue crabs.

	Soft Blue Crab[1]	Hard Blue Crab[2]
Moisture	84.68 ± 0.25	80.3 (77.4 – 86.7)[3]
Protein	10.91 ± 0.53	15.9 (8.6 – 19.8)
Fat	1.40 ± 0.06	1.3 (0.4 – 2.2)
Ash	2.84 ± 0.10	1.9 (1.3 – 2.7)
Total	99.83	

[1]Each soft crab mean value and standard deviation (±) represents eight replicates where one replicate is for one whole crab blended for analysis.
[2]Source: Sidwell (1981)
[3]Range

The mineral composition is likewise a reflection of the higher proportion of shell material and the metabolic state immediately post-molt (Table 3). The sodium (Na), calcium (Ca) and phosphorus (P) content in the soft crabs was substantially higher than that reported for raw hard crab muscle tissue (Sidwell 1981). These concentrations reflect the osmotic state of the crab and the high calcium content can be explained as a necessary constituent for shell formation and hardening. The microminerals are similar to previous reports except for the lower concentrations of zinc (Zn) and copper (Cu). These minor minerals are primarily associated with muscle growth and function, thus they should be initially low due to the lower proportion of protein found in soft crabs. There was no detection of mercury (Hg) or cadmium (Cd) with detection methods limited to 0.01 μg/mℓ.

TABLE 3.

Mineral analysis for whole, raw blue crabs.

Minerals	Soft Blue Crab[1]	Hard Blue Crab[2]
	mg/100 g	
Na	486.4 ±23.57	337
K	249.71 ± 6.89	244 (188 – 299)[3]
Ca	422.35 ±47.79	115 (60 – 277)
P	309.14 ±52.46	174 (38 – 272)
Mg	64.53 ± 3.55	32 (12 – 47)
	ppm	
Fe	22.0 ± 1.0	23.17 (2 – 54)
Cu	4.28 ± 0.55	9.36 (1.3 – 19.0)
Zn	18.8 ± 0.8	40.24 (34 – 46)
Mn	6.00 ± 0.78	
Cd	ND[4]	
Hg	ND	

[1]Each soft crab mean value and standard deviation (±) represents eight replicates where one replicate is for one whole crab blended for analysis.
[2]Source: Sidwell (1981)
[3]Range
[4]Not detected

The fatty acid profile is similar as for most lean varieties of seafoods (< 2% lipid) with a high concentration of polyunsaturated acids (Table 4). The monosaturates and polyunsaturates constituted 21.48% and 33.26% of the total fatty acids, respectively. In comparing the polyunsaturates to saturates ratio for soft crabs (PUFA/SAT, 1.48) the soft crabs appear more saturated than raw hard crab meat (1.34; Sidwell 1981) and pasteurized crab meat (1.32; Gruger et al. 1964). Apparently, the postmolt condition does not significantly influence the total fat content, but does alter the fat composition (compare Tables 1 and 4).

These basic nutritional constituents in raw soft crabs would be altered by cooking as reported for other seafoods (Mai et al. 1978, Gall et al. 1983). If breaded and fried, the customary method of preparation, the soft crab moisture content should decrease causing a slight increase in protein

TABLE 4.

Fatty acid profile (% composition of total fatty acids) for whole, raw soft blue crabs.

Fatty Acid	Percent[1]
14:0	3.99 ± 0.48
14:1 ω 9 + 15:0	3.21 ± 0.50
16:0	18.75 ± 0.90
16:1 ω 9	8.59 ± 0.39
17:0	3.62 ± 0.37
18:0	3.54 ± 0.61
18:1 ω 9	9.68 ± 0.69
19:0	0.53 ± 0.30
18:2 ω 6	1.62 ± 0.73
20:0	0.99 ± 0.40
20:1 ω 9 + 18:3 ω 3	5.39 ± 0.80
20:2 ω 6	1.60 ± 0.39
22:0	0.54 ± 0.24
20:3 ω 6	0.30 ± 0.14
20:4 ω 6	5.43 ± 0.23
22:2 ω 6	2.14 ± 0.14
20:5 ω 3	7.35 ± 0.31
22:3 ω 6	0.27 ± 0.19
22:4 ω 6	1.25 ± 0.36
22:5 ω 3	1.18 ± 0.07
22:6 ω 3	6.76 ± 0.47
Others	8.31 ± 0.82
Total	100.04

[1]Each mean value and standard deviation (±) represents eight replications where one replicate is one crab blended for analysis.

content. These changes would not represent a major alteration in the nutritional value. The addition of calories from breading and absorbed frying oil would cause the most significant changes. The fat content and composition per serving would increase and change to reflect the character of the frying oil. Likewise, the breading formulation could dominate the mineral composition, particularily sodium content. Fried soft crabs would represent a seafood with a relatively high salt content. Based on the raw composition, 486 mg Na/100 g crab (Table 4), plus additions from breading and cooking dehydration, a fried soft crab could provide in excess of 130 mg sodium per 4-ounce serving. In general, fried soft crabs should be considered a typical lean variety of fried seafood with a higher-than-average amount of sodium. Persons on a low-sodium-restricted diet may consider alternative nonfried recipes and/or consumption in moderation.

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REFERENCES CITED

Andree, S. 1985. Report on soft crab activities in Florida. *Proc. of the National Symposium on the Soft-Shelled Blue Crab Fishery*. 96–99.

Association Official Analytical Chemists (AOAC). 1980. *Official Methods of Analysis*. 13th edition. Washington, D.C.

Gall, K. L., W. S. Otwell, J. A. Koburger and H. Appledorf. 1983. Effects of four cooking methods on the proximate, mineral and fatty acid composition of fish fillets. *J. Food Sci.* 48:1068.

Gruger, E. H., R. W. Nelson and M. E. Stansby. 1964. Fatty acid composition of oils from 21 species of marine fish, freshwater fish and shellfish. *J. Am. Oil Chem. Soc.* 41:662.

Mai, J., J. Shings, J. Weihrauch and J. E. Kinsella. 1978. Lipids of fish fillets: Changes following cooking by different methods. *J. Food Sci.* 43:1669.

McCreary, D. K., W. S. Kossh, S. Ramachandran and R. R. Kurtz. 1978. A novel and rapid method for the preparation of methyl esters for gas chromatography: Application to the determination of the fatty acids in edible fats and oils. *J. Chromatog. Sci.* 16:329.

Sidwell, V. D. 1981. *Chemical and Nutritional Composition of Finfishes, Whales, Crustaceans, Mollusks, and their Products.* U.S. Dept. Comm., National Marine Fisheries Service Tech. Mem. NMFS F/Sec–11. 432 p.

U.S. Food and Drug Administration. 1978. *Bacteriological Analytical Manual.* 5th edition, Association of Official Analytical Chemists. Washington, D.C.

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985, 81–104.

REPORTS OF STATE ACTIVITIES

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985, 83.

THE SHEDDING POTENTIAL IN DELAWARE

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PRESENT SITUATION

Although there are no recorded landings for soft crabs in Delaware, crabs are shed within the state. At the present time, Delaware has only five small shedding operations. Of these, there are no full-time operations. One is located in the northern part of the state, two are centrally located, and two are located in the lower end of the state. Shedding tables range in number from a low of two to a high of eight. All are open systems, although a closed system will be built in the northern part of the state this spring.

Most of the shedders in the state of Delaware rely on the peeler harvest from Delaware Bay. Herein lies the major problem for those in the shedding business. Although there are quite a large number of commercial crabbers, Delaware law severely limits the type of gear that is legal for crab harvesting. Consequently, Delaware does not have a large number of crabbers that produce peelers. This leads to the real crux of the Delaware situation, the potential for crab shedding within the state.

POTENTIAL

Delaware is located centrally in the mid-Atlantic region. Based on this fact alone, the problem of peeler supply is easily overcome. Several of the largest peeler-producing areas on the Eastern Shore are less than a 2-hour drive from almost any point in the state. Peelers may be obtained from any of the following locations in Maryland: Ocean City, Crisfield, Deal Island, Cambridge, Kent Island, or Chestertown. Buying the peelers from these areas will also permit the Delaware shedder to operate at the height of the season and effectively compete in the marketplace. Buying peelers from Maryland producers will also eliminate the lag time (approximately 2 to 4 weeks) between Maryland and Delaware harvest. During the 1984 season, one Delaware shedder was able to purchase peelers at $0.30 apiece from Maryland. It is felt that this type of arrangement could be found in each of those areas mentioned above which would provide a great deal of security in the event that the peeler harvest from Delaware Bay was small.

There are many locations within the state that are suitable for shedding operations. In the lower part of the state, real estate prices are at a premium. Consequently, the middle and northern portions of the state would require less capital for startup due to the lower costs for real estate. The majority of these areas are suitable for open systems.

Delaware's location is prime for the marketing of soft-shelled crabs. In the lower part of the state, there is an extremely large tourist industry. Quite a large part of this industry is made up of restaurants and seafood markets. Many of these businesses are seasonal and are always actively searching for sources of soft-shelled crabs. In terms of wholesale marketing, shedders in Delaware are less than 3 hours away from New York, Philadelphia, Baltimore, Washington, or Norfolk. Dual highways run the length of the state making truck travel quite easy. Many airports are also in close proximity to Delaware, thereby opening the possibilities of expanding the markets to other parts of the country.

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CRAB SHEDDING IN MARYLAND: REFLECTIONS – PREDICTIONS

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INTRODUCTION

Soft crabs are many things to many people. To a waterman, soft crabs might be extra income during the crabbing season. To a waterman's wife and family, soft crabs might be more work and less sleep during the summer. To a crab shedder, soft crabs are a full-time job with many sleepless nights. Soft crabs are a favorite summertime meal for many seafood fanciers and are often frozen for wintertime consumption. Many species of fish also enjoy a tasty meal of soft crab, thus, soft crabs are a widely used bait by many sport fishermen.

In Maryland, soft crabs and their percursors, peelers, have been an important part of the blue crab fishery for more than 100 years. A good year in Maryland might produce more than 3 million pounds (approximately $14.4 million) of soft crabs. Recent years have seen dramatic changes in the shedding industry as shedding systems have evolved technologically. The future is, yet, unbounded as shedding systems continue to evolve, mortalities continue to decline, and the demand for soft crabs continues to rise.

There are two predominant methods currently used in Maryland to shed crabs: flow-through and closed systems. Flow-through systems are located along shorelines and rely on nature to furnish water of acceptable quality to the shedding crabs. Water is pumped from the estuary into the shedding tanks and drained back to the estuary. High water temperatures, excessive silt and, possibly, chemical pollutants are the major water quality problems associated with flow-through systems.

Closed systems are self-contained units that use a series of filters to clean recirculating water. Most problems associated with closed shedding systems center around a biological filter which uses nitrifying bacteria to remove toxic, nitrogenous crab wastes from the recirculating water. A major advantage of closed shedding systems is the system is self-contained, therefore, it can be located anywhere the crab shedder wants the closed system. The closed system also offers control over water quality; control that is not economically possible in a flow-through system.

HISTORY OF CRAB SHEDDING IN MARYLAND

Because written history often lacks perceived minor events, the original taster of soft crabs has probably been long forgotten. To provide a brief history of crab shedding in Maryland, a time line has been drawn to graphically show the progression of events (Figure 1).

There should be little doubt that the Crisfield/Deal Island area of Maryland was and still is a major contributing force in the soft crab industry. It is said that two events in 1870 revolutionized the soft crab industry: John Landon and Severn Riggin experimented with holding hard crabs in pounds, and L. Cooper Dize patented the crab scrape. Efforts to hold hard crabs until they molted evolved from pounds to floats placed inside of pounds for protection from wind and wave action (Warner 1976). The combination of floats for holding large numbers of peelers and scrapes for gathering large numbers of peelers blossomed into a prospering industry for those willing to work hard and gamble with Mother Nature.

Business was good in the Crisfield/Deal Island area, so good that in 1910, some 13 million soft crabs valued at approximately $2 million were sold (Warner 1976). Most of these crabs were destined for New York's Fulton Market and points beyond. The consuming public demanded fresh soft crabs and, in the early 1900s, ice was used to ensure fresh shipments of soft crabs out of Crisfield. Warner (1976) reports that after World War I, the Chesapeake Bay area was the primary supplier to Fulton Market.

Crab mortalities were high at times, but the demand for soft crabs kept the shedders going. Often as many as 50% of the peelers placed in a float died (Warner 1976). In 1938, the mortality issue was studied by Beaven and Truitt (1938) at the Chesapeake Biological Laboratory. Poor post-harvest care to peelers before placing them in floats, poor pound locations, nicking (the breaking of the tip of the claw), and the use of green crabs were among the major reasons given by Beaven and Truitt (1938) for high mortalities in shedding floats. Beaven and Truitt (1938) estimated that approximately 5 million crabs were lost in the shedding process in 1938 and concluded: "... the recent practices in the industry [crab shedding] are definately (sp) injurious."

Around 1950, Wellington Tawes moved his floats onto land, presumably to make the job of shedding a little easier and to improve the circulation of water through the floats by pumping the water (Warner 1976). The new method was probably slow to catch on initially, as old-timers scoffed the idea. After a few brave souls made a few extra dollars, use of the method spread quickly around the area. The Handy Company in Crisfield was the first to try a large

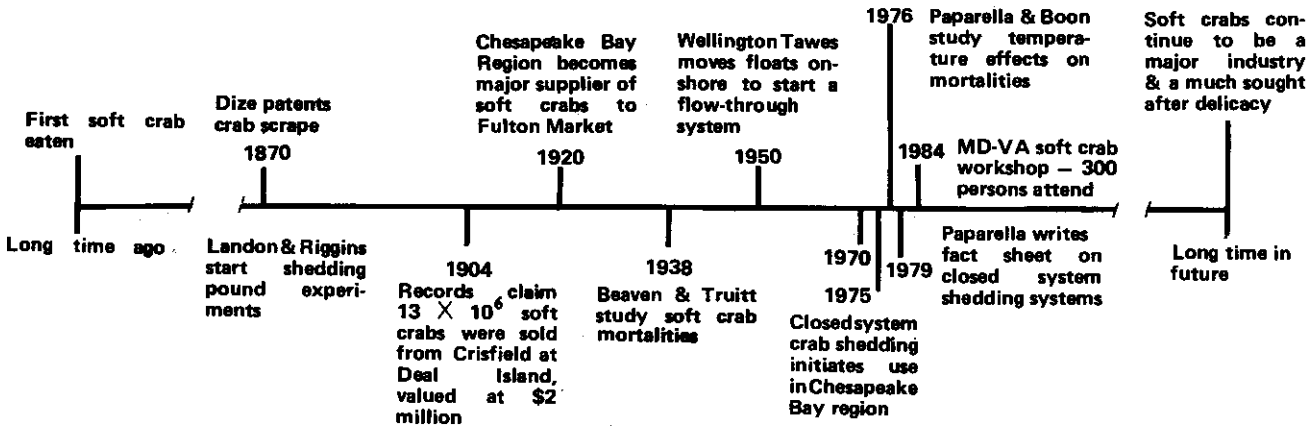

Figure 1. History of crab shedding in Maryland.

indoor flow-through system (Warner 1976). This new method, called flow-through systems by scientific types, slowly replaced floats placed overboard and now is probably the most popular system of shedding crabs.

Science and technology had a way of creeping up on crab shedding and in the early-to-mid 1970s, another system was developed to shed crabs using the same water over and over again. The creator of closed systems remains anonymous in Maryland, but one individual, Mike Paparella, was instrumental in providing much needed information about closed-system crab shedding. Paparella (1976, 1979, 1982) wrote several fact sheets explaining the various components of a closed shedding system.

The Marine Advisory Program in Maryland initiated its soft crab project in 1982. System design parameters are being studied and continually changed as more knowledge is gained about soft crabs. Crab shedders interested in establishing or modifying closed systems have been provided with engineering assistance. Water quality monitoring and testing procedures have been established and a water quality data base has been started. This data base will be used to determine the effects of water quality on shedding mortality. In 1984, a closed system crab shedding workshop, sponsored by Marland and Virginia Marine Advisory Programs, was held in Salisbury, MD. Over 300 interested people attended the workshop to learn about closed system crab shedding.

A final bit of history which offers an important sense of perspective on crab shedding in Maryland, especially as it is related to the activities of those in the scientific and extension communities, is landings data. Table 1 shows crab landings for Maryland compared to several other states in total pounds and dollar value of the catch. Several interesting observations can be made from these data. When prices are compared, the southern states show a decided advantage. It is easy to see why the recent interests in crab shedding are spreading throughout the south. If landings are compared, then, at least in this time period, Maryland out-produces all other states combined. In Table 2, the Maryland landings from 1970 to 1983 are shown. One must note that, in 1981, a different reporting method was used to provide better estimates of the landings.

PRESENT EFFORTS IN MARYLAND

Both flow-through and closed systems can be successful for shedding crabs profitably, but both systems suffer periodic bouts of high crab mortalities. High water temperatures and silt appear to be the lethal elements in flow-through systems. Closed systems are deadly to crabs when improperly started up. Biofilter failures due to poor acclimation, clogging, and overloading are responsible for periods of excessively high mortalities.

At the present time, soft crab work in Maryland consists of several demonstration projects by an extension specialist. Research and extension efforts in the past have been sporatic; individual; and, for the most part, limited to minimal support. This trend is slowly changing as major research and extension programs are slowly emerging. Present support to the crab shedding industry includes:

- ***Water Quality Monitoring*** – A water quality monitoring program was started in 1983 to establish relationships between water quality and shedding mortalities in closed systems. Dissolved oxygen, water temperature, pH, ammonia, nitrite, nitrate, salinity, total number of crabs in the system, and mortality data were collected. This program will continue so that better models of the relationships among the various water quality parameters and mortalities can be formulated.
- ***Demonstration Shedding Systems*** – Two demonstration

TABLE 1.

Crab landings – comparison of Maryland to other states.

	New Jersey		Delaware		Maryland		Virginia		North Carolina		Louisiana	
Year	10^3 pounds	$/lb	10^3 pounds	$/lb	10^3 pounds	$/lb	10^3 pounds	$/lb	10^3 pounds	$/lb	10^3 pounds	$/lb
1970	18	0.24	na	na	1,179	0.42	909	0.37	59	0.39	89	0.90
1971	15	0.33	9	0.56	1,530	0.48	693	0.46	49	0.51	127	0.99
1972	15	0.30	10	0.80	1,575	0.48	858	0.48	50	0.58	102	1.07
1973	23	0.67	18	0.72	1,513	0.50	983	0.51	45	0.62	119	1.11
1974	126	0.42	73	0.71	1,822	0.57	814	0.49	33	0.70	96	1.32
1975	39	0.41	34	0.71	1,654	0.53	754	0.51	20	0.85	119	1.30
1976	90	0.44	na	na	1,474	0.73	761	0.72	20	1.32	88	1.65
1977	5	0.53	na	na	1,512	0.92	695	0.84	16	1.06	225	2.53
Average 1970–1977	41		29		1,582		808		37		121	

TABLE 2.

Soft crab landings in Maryland, 1970–1983.

Year	Landings (10^3 pounds)
1970	1,579
1971	1,530
1972	1,563
1973	1,497
1974	1,812
1975	1,642
1976	1,464
1977	1,141
1978	853
1979	933
1980	1,133
1981	897
1982	2,475
1983	3,526

closed crab shedding systems have been built. One, located at Horn Point Environmental Laboratory, was built for hands-on workshops and demonstrations of closed crab shedding systems, and for use as a testing facility to validate new proposed modifications in shedding systems. Another system was built in Kent County, Maryland, to provide the northern Eastern Shore counties with a local demonstration facility. More demonstration facilities will be sought in the future, especially on the lower Eastern Shore and Western Shore of Maryland.

- ***Workshops and Personal Help*** – Closed system design and water quality monitoring is conveyed to interested and prospective shedders in both workshop and one-on-one settings. With the demonstration facilities providing an excellent teaching aid, many questions are answered and problems analyzed. Water quality assistance is also available for those shedders with serious system problems.
- ***Biofilter Conditioning and Recovery from Failure*** – Techniques are being studied to aid crab shedders in the efficient start-up of closed systems. One of the major problems in closed system shedding is the heavy mortalities associated with starting the system at the beginning of the season. Artificial conditioning methods for the biofilter could be profitable to the crab shedder by decreasing initial mortalities at a time when soft crabs typically bring a premium price. A rapid, inexpensive method of restarting a failing biofilter is also being examined. Mid-season biofilter failure can cause several weeks of high mortalities.
- ***System Design Criteria*** – As new design criteria become available, technology updates are compiled and disseminated to keep established and potential shedders aware of these criteria.
- ***System Management*** – Closed system management techniques are being developed and disseminated to crab shedders. Once a system is built, the majority of the problems associated with closed system crab shedding involve system management decisions. These include, but are not limited to: water quality testing, system startup, biofilter maintenance, peeler purchasing strategies, and marketing strategies.

FUTURE NEEDS – PREDICTIONS

Closed system crab shedding will continue to evolve and be refined until close to ideal shedding success is achieved. This process of evolution can only occur if there is commitment between shedders and the scientific communities. At the present time, this linkage exists, but we must nurture the bond to continue the success record of the past few years.

Several major areas come to mind when the future is pondered. System management needs to become almost cookbook, instead of guesswork. Crab shedders need to learn how to manage their systems efficiently and economically, just because it was always done a certain way does not make it cost effective. Water quality testing needs to

become a daily routine. By watching the crabs, a shedder might be able to tell that something is wrong but he can rarely tell what specifically is wrong.

The trend to closed systems will continue as increased water quality control will lead to decreased mortalities. Closed systems will become more understood and design based on factual criteria rather than best guesses will be the rule. Flow-through systems will not be totally eliminated. In fact, they too will be refined and improved. As the waters of the Chesapeake recover from the years of abuse, flow-through systems will enable shoreline locations alternate possibilities for system design.

Sometime in the near future, all of those efforts to reduce mortalities will lead to additional problems in the area of marketing. New domestic and overseas markets need to be established. Marketing strategies also need to be developed. Concurrently, quality control measures and standards need to be established from within the industry and not dictated to it.

Processing techniques must be examined to determine optimal fresh and frozen products. Storage requirements need to be analyzed so that maximum shelf life and product quality are obtained.

The future will require the collective efforts of many individuals and groups. Industry people must get together, communicate, and organize. The potential exists for the traditional shedder to modernize yet retain the individuality and the traditions most sought by the waterfront community. Researchers must also continue to exchange ideas rationally as they are today. The future of crab shedding truly looks bright and promising.

BIBLIOGRAPHY

The following is a list of soft crab literature that provide good references for those interested in obtaining more information.

Beaven, G. F. and R. V. Truitt. 1938. Crab mortality on Chesapeake Bay shedding floats 1938–1939. Chesapeake Biological Laboratory.

Cupka, David M. and W. A. Van Engel. 1979. *Proceedings of Workshops on Soft Shell Blue Crabs.* South Carolina Marine Resources Center Technical Report No. 48, Virginia Institute of Marine Science Contribution No. 1003.

Haefner, Paul A., Jr. and David Garten. 1974. Methods of handling and shedding blue crabs, *Callinectes sapidus.* Marine Resources Advisory Serv. No. 8, Spec. Rep. in Applied Marine Science and Ocean Engineering No. 52.

Haefner, Paul A. Jr., W. A. Van Engel, and David Garten. 1973. Rock crab: a potential new resource. Virginia Marine Resources Advisory Series No. 7.

Jachowski, Richard L. 1969. Observations on blue crabs in shedding tanks during 1968. Natural Resources Institute of the University of Maryland, Ref. No. 69–24.

Kumar, Sunil. 1984. Closed recirculating nitrification systems for soft shell crabs. Louisiana State Univ. and Agricultural and Mechanical College, Dept. of Civil Engineering. Thesis.

Lakshmi, G. J., Christine M. Trigg, Harriet M. Perry, and A. Venkataramiah. 1984. The effect of ammonia accumulation on blue crab shedding success. Mississippi-Alabama Sea Grant Consortium, Ocean Springs, MS. Project No. R/RD–2, MASGP–83–023.

Landrum, Paul D. and Fred J. Prochaska. 1980. The Florida commercial blue crab industry: landings, prices and resource productivity. Florida Sea Grant College, Rep. 34.

Malone, Ronald F. and Don P. Manthe. 1984. Interim design recommendations for closed-recirculating blue crab shedding systems. Dept. of Civil Engineering, Louisiana State Univ.

Manthe, Don P., Ronald F. Malone and Sunil Kumar. 1984. Limiting factors associated with nitrification in closed blue crab shedding systems. *Aquacultural Engineering* 3.

Manthe, Don P. 1983. Soft shell crab project. Progress Rep., Louisiana State University.

Millikin, Mark R. and Austin B. Williams. 1984. Synopsis of biological data on the blue crab *Callinectes sapidus* Rathbun. *FAO Fish. Synop.* 138.

Oesterling, Michael J. 1984. Manuel for handling and shedding blue crabs. *Appl. Mar. Sci. Ocean Engr.* 271. Virginia Sea Grant Program.

Oesterling, Michael J. 1982. Mortalities in the soft crab industry: sources and solutions. Virginia Sea Grant Program, Mar. Res. Rep. 82–6.

Ogle, John T., Harriet M. Perry, and Larry Nicholson. 1982. Closed recirculating seawater systems for holding intermolt blue crabs: literature review, systems design and construction. Mississippi Bureau of Marine Resources. Tech. Rep. Ser. No. 3.

Otwell, Steve. 1980. Harvest and identification of peeler crabs. Florida Sea Grant Publication, MAFS–26.

Paparella, Michael. 1976. Information tips to improve the processing of seafood. Marine Products Laboratory, Crisfield, MD, and Center for Environmental and Estuarine Studies.

_____. 1979. Information tips to improve the processing of seafood. Marine Products Laboratory, Crisfield, MD, and Center for Environmental and Estuarine Studies.

_____. 1982. Information tips to improve the processing of seafood. Marine Products Laboratory, Crisfield, MD, and Center for Evironmental and Estuarine Studies.

Perry, Harriet M., John T. Ogle and Larry C. Nicholson. 1979. The fishery for soft crabs with emphasis on the development of a closed recirculating seawater system for shedding crabs. *Proc. Blue Crab Colloquium* 7:137–152. Available from the Gulf States Marine Fisheries Commission, Ocean Springs, MS 39564.

Sieling, Fred W. The Maryland blue crab. State of Maryland, Dept. of Natural Resources, Public Information Serv.

Van Den Avyle, Michael J. and Dean L. Fowler. 1984. *Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (South Atlantic) – Blue Crab.* U.S. Dept Int., Fish Wildl. Serv., FWS/OBS–82/11.19.

Warner, William W. 1976. *Beautiful Swimmers.* Murray Printing Co., Penquin Books Ltd.

Wescott, Wayne. 1984. *A Guide to Soft Shell Crabbing.* Univ. North Carolina Sea Grant College Publ. UNC–SG–84–01.

REFERENCES CITED

Beaven, G. F. and R. V. Truitt. 1938. Crab mortality on Chesapeake Bay shedding floats 1938–1939. Chesapeake Biological Laboratory.

Paparella, Michael. 1976. Information tips to improve the processing of seafood. Marine Products Laboratory, Crisfield, MD, and Center for Environmental and Estuarine Studies.

_____ . 1979. Information tips to improve the processing of seafood. Marine Products Laboratory, Crisfield, MD, and Center for Environmental and Estuarine Studies.

_____ . 1982. Information tips to improve the processing of seafood. Marine Products Laboratory, Crisfield, MD, and Center for Environmental and Estuarine Studies.

Warner, William W. 1976. *Beautiful Swimmers.* The Murray Printing Co., Penquin Books Ltd.

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985, 89–90.

THE VIRGINIA SOFT CRAB FISHERY AND ASSISTANCE INITIATIVES

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The Virginia soft crab fishery ranks second nationally in poundage and value behind our Chesapeake neighbor Maryland. Historically, it is difficult to separate the development of the Virginia and Maryland soft crab industries. Their parallel development is evidenced by great similarities in the soft crab fisheries of the two states. As a result, whenever the total United States soft crab industry is discussed, the production of Virginia and Maryland are frequently combined and reported as Chesapeake Bay soft crab landings.

The Chesapeake Bay states are by far the major soft crab producers. For the 5 years from 1980 through 1984, Chesapeake Bay produced on the average of about 94% of the total U.S. poundage and about 92% of the value of all reported soft crabs. By states, Maryland produces about 74% of the reported pounds, Virginia 20%, and for value, Maryland 75% and Virginia 17%.

The word "reported" must be emphasized in reported soft crab landings. The landings data for soft crabs nationwide must be examined knowing that they do not accurately represent the magnitude of the industry. Virginia is no exception to this rule. Although the Virginia Marine Resources Commission (the state regulatory agency) recognizes the value of the soft crab fishery to the state and does make an effort to obtain accurate data, due primarily to monetary constraints, it has not adequately collected soft crab landings. A case in point, Virginia landings do not include any Tangier Island production. This is thought to be a substantial amount. The majority of Tangier production is sold in nearby Crisfield, MD, and, hence, gets reported as Maryland soft crabs.

With this in mind, for the past 5 years, the reported soft crab landings for Virginia have averaged 707,000 pounds, valued at $828,000. The production in 1984 was substantially more than the 5-year average, at 872,800 pounds, valued at over $1,012,000.

Soft crabs are produced throughout tidewater Virginia and its eastern shore. However, the eastern shore has the largest shedding facilities within the state. The Virginia soft crab industry is composed of a wide spectrum of operations, running the gamut from ma-and-pa to large businesses producing over 50,000-dozen soft crabs annually. The exact number of soft crab producers in Virginia is unknown. There are minimal licensing requirements for shedding facilities and, in some cases, no licenses at all are needed. A continuing activity of the Virginia Marine Advisory Service has been to characterize the soft crab industry and to develop better economic information about its participants.

The harvesting of peelers is the number one constraint to the development of a soft crab fishery. Virginia is fortunate in having a history of peeler capture. Within Virginia many techniques are used to catch peelers. Peelers are harvested by pots (both regular hard crab and peeler pots), by peeler pounds (a type of shore fyke), by scrapes (a modified dredge without teeth), by dip-netting off of pilings, fish pound net leads or from the bottom, and by a method known as mud-larking (collecting peelers from pools in a marsh at low tide).

Soft crabs are shed in traditional wooden in-water floats, shore-based flow-through tanks, and closed recirculating water systems. Many times these methods are used in combination or at different times of the year. Some of the largest volume soft crab producers may use as many as 125, 4- × 8-ft shedding tanks, each capable of holding approximately 300 crabs at one time.

The Virginia Marine Advisory Service has a continuing commitment towards the soft crab fishery that began before the existence of the Sea Grant program. Prior to the inception of Sea Grant, soft crab producers could receive technical assistance through the Virginia Institute of Marine Science (VIMS). With the creation of the Sea Grant program and the placement of its Advisory Service at VIMS, it was natural for the Advisory Services to assume these activities. In fact, Virginia was the first Sea Grant program to begin directly assisting the soft crab industry. The first published instructional materials on soft crab production and closed systems came from the Virginia Marine Advisory Service in the early 1970's. Then, last year it published the most comprehensive manual on soft crab production to date.

Current Advisory Service assistance to the soft crab industry falls into two broad areas: industry encouragement and industry expansion. The main goal of these is to increase the production capabilities of the soft crab industry. Toward this goal there are four categories of activities within which there are programs: basic education; diagnostic services; shedding facility design/construction; and product promotion. All of these categories are conducted in the

broad areas of encouragement and expansion, with just the level of information being disseminated differing.

Basic educational activities are conducted in mass gatherings such as seminars and workshops, and on a one-to-one basis. Seminar activities have included programs in Virginia as well as in other states and have been sponsored either solely by Virginia or in cooperation with other states. With the Chesapeake Bay soft crab industry being the pattern everyone else is trying to copy, the Virginia Advisory Service is called upon to share its expertise with other states.

Much of Virginia's Advisory activities fall into the one-on-one type of information exchange. This is regardless of whether it is encouragement or expansion activities. Individualized assistance is provided to prospective industry members and established producers, on such topics as facility construction, peeler capture, facility conversions and marketing. These one-on-one information activities spill over to diagnostic services. Free analysis of basic water quality parameters within shedding facilities are provided upon request to the soft crab producer.

Because Virginia has an established soft crab fishery, a great deal of effort has been directed toward industry expansion and facility conversions.

For the past few years Virginia has had an active program assisting in the installation of recirculating systems. Virginia closed systems employ a large, single-medium biological filter and a protein skimmer to maintain water quality. The biological filters are generally the bottom half of a 500- to 1000-gallon septic tank, sunk in the ground. Within this tank are placed trays of oyster shell which serve as filter medium and buffering agents.

Protein skimmers are constructed of PVC pipe and require no compressed air for foam generation. By elevating the skimmer and using an orifice venturi, gravity and atmospheric air generate foam and redistribute water.

The efforts in closed systems have been very successful. The Virginia Marine Advisory Service has assisted producers in increasing their soft crab survival by using closed systems and people without waterfront property are shedding crabs commercially. At this time, the largest closed system for soft crab production is located in Virginia. This system has 81, 4- × 8-ft shedding tanks, with three biofilters and three protein skimmers.

Even though Virginia has been successful in establishing viable closed system production facilities, assistance efforts continue. There are three areas in which there are currently ongoing projects with recirculating systems. The first of these is the fine tuning of the biological filters, looking at such things as optimum size, configuration and medium type. Along with this are activities dealing with the problem of shock loading. The number of peelers caught in Chesapeake Bay from one day to the next can fluctuate widely and quickly. This means that the number of peelers added to a closed system can change overnight from a few hundred to a few thousand. This tends to overwork the biological filter bacteria, decreasing their efficiency.

In the development of closed system crab shedding there have been questions as to the need for protein skimmers. Unfortunately, the effectiveness of skimmers has never really been documented. Another project hopes to identify how useful protein skimmers are for maintaining water quality within shedding systems.

In somewhat of a departure from other programs, there is a project promoting nontraditional use of shedding systems. The Virginia shedding season only lasts from April to November, leaving almost 6 months that shedding facilities are unused. An exciting activity is the work on rock crab (*Cancer irroratus*) shedding. Rock crabs shed during winter, a time when traditional soft crab producers are idle. Through the efforts of the Marine Advisory Service soft rock crabs are now being shed commercially in Virginia. While the aforementioned manual on shedding did contain a chapter on rock crabs, there will be a separate publication on soft rock crab production available in the next few months.

The United States may no longer be the only producers of soft crabs. Our neighbors to the south, Mexico and Central America, have been actively trying to develop a soft crab fishery. When these areas enter into soft crab production, they most likely will look to established markets to sell their product. If past experiences with other seafood items hold true, this means the United States. For Virginia's industry to maintain its superior market position, more emphasis must be placed on the production and promotion of high quality soft crabs. Additionally, the development of new markets and marketing strategies must be pursued. Soft crabs are being aggressively promoted domestically and overseas through the efforts of the Virginia Marine Products Commission, two fishery development foundations, the Virginia Marine Advisory Service and private individuals.

The Virginia Marine Advisory Service and other agencies offer a complete program for the soft crab industry, providing assistance in every facet of the fishery from initial production to final marketing.

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985, 91–92.

NORTH CAROLINA SOFT CRAB INDUSTRY

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The soft crab industry in North Carolina has definitely had its ups and downs over the years. Although no one is sure just when the soft blue crab was first harvested and sold commercially, NC landings are recorded as far back as 1897. These landings were relatively stable from 1900 until the early 1950's with the exception of a bumper year in 1928 (629,000 pounds). In the late 1950's, emphasis shifted to the hard blue crab and continued through the 1960's and 1970's. Soft crab production fell drastically during those years with a low of 16,000 pounds recorded in 1977. It should be noted that the North Carolina Division of Marine Fisheries compiles landings statistics from landings of peelers that pass through crab dealers. Because most of the soft crab production in North Carolina is directly from the crabber to the shedder, recorded landings are grossly understated. However, recorded statistics were gathered in the same manner each year, therefore overall trends are reflected.

In the late 1970's, a few local soft crab shedders had very profitable years and an interest in soft crabs was rekindled. Recorded landings rose from 16,000 pounds in 1977 to 166,000 pounds through July 1984. Profits from the sale of soft crabs continued to be good and the fishery is continuing to expand. More and more local fishermen, dealers and private citizens wanted the latest information about peeler harvesting methods, peeler identification, soft crab shedding facility design, packaging and marketing.

In 1981, North Carolina's Sea Grant program, through the marine advisory personnel, began to gather soft crab information from local shedders, researchers, other state shedders, and their advisory people to meet the information needs of North Carolina. Before that time, information requests were usually handled by arranging appointments with existing shedders who, in turn, would answer the questions. Today, the interest in shedding crabs and the request for information has grown so large that all of the North Carolina commercial fishery agents are somewhat knowledgeable about the subject and one Area Marine Specialist dedicates 50% of his time exclusively to the soft crab industry.

Today in North Carolina the soft crab industry is on the rise. Crabbers use dip nets, trotlines, crab pots, peeler pots, habitat pots, trawl nets, bushlines, and peeler pounds to harvest soft crabs and peelers. The peeler pot and peeler trawl are the most productive, however, in some areas, they are ineffective and the other types of gear must be used to harvest peelers.

Many shedders both catch peelers and buy them from commercial crabbers who supplement their incomes from hard crabs by selling the incidental catches of peelers. Some crabbers reap profits exclusively from peeler sales for a short 2- to 3-week season during the major or first run. Most of these peelers are shed in flow-through systems, but floating and closed or recirculating systems are also successful. In 1984, the fresh well-water, temperature-controlled recirculating systems were built and show excellent potential. This system permits the shedding of soft crabs early in the year because the water in the system can be warmed. Also, this system reduces mortality later in the summer because the water can be cooled. Both electrical and solar heating devices are used to warm the water and adding additional ground water is used to cool the system. Frequent dilution of the system prevents buildup of toxics resulting in low peeler mortality.

Before 1980, North Carolina's Sea Grant personnel distributed some printed materials and arranged site visits with existing shedders. Since that time, however, demand has necessitated the development of a more comprehensive soft crab program. Grants have been issued to study problems of crab mortality and alternative harvesting gear. Slide shows have been developed depicting peeler harvesting gear, identification, facility design, packaging and marketing of both live and frozen soft crabs. A *Guide to Soft Shell Crabbing* has been written and distributed to over 3,000 people. A number of local presentations, workshops, and regional seminars have been conducted and requests for information warrant their continuation.

Presently North Carolina's Sea Grant program is continuing research into causes of peeler mortality, effects of artificial grass within existing peeler pots, and the success and profitability of the fresh well water recirculating shedding system. Also, because more peelers are caught in crab pots than any other type of gear and returned to the deep because they are too small to sell as hard crabs, educating the hard crab fisherman is a must. This will provide the crabbers with substantial additional income and, at the same time, increase the availability of peelers and, thus, profits to the shedders.

In 1984, Dare County alone produced over 225,000 pounds of soft crabs and landings of hard crabs were not

impaired. We plan to share the latest research and technology with the other coastal communities of North Carolina where soft crab shedding is underutilized. We know that peelers are present, crabbers exist and numerous shedding sites are available. Development of the soft crab industry in central and southern North Carolina is our goal. Also, to improve the efficiency of existing soft crab facilities is a continuing endeavor.

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SOFTSHELL CRAB INDUSTRY IN SOUTH CAROLINA

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HISTORY

Production of softshell crabs has been documented in South Carolina since the 1930's. A peak production of 9,000 pounds was reported in 1936, but production steadily declined to 400 pounds in 1957 and no production was reported again until the late 1970's. The decline of the softshell crab industry coincides with an increase in hard crab landings with the introduction of crab pots to the South Carolina fishery in 1955. Hard crab production has continued to increase while softshell crab declined to a small incidental portion of the commercial hard crab fishery and no shedders operated.

In 1979 interest was again generated in shedding operations through two regional workshops in Charleston, SC, in 1977 and 1979. Production has increased to 10,000 pounds in 1984 exceeding the previous peak of 1936. Production has fluctuated in the period from 1979 to 1984 due to inconsistencies in shedding operations entering and exiting the industry.

In 1984, 13 licenses for softshell crab operations were issued and 10,000 pounds of softshell crabs were produced, valued at $50,000.

One major operator accounts for the majority of the production and has plans to remain in operation.

All of South Carolina's four major blue crab processing plants have been engaged in softshell crab production at some time during the past decade. No plant has maintained a sustained shedding operation. South Carolina crabmeat processors must utilize crabs with a legal size of 5 inches or greater; therefore, crab shedding is reduced due to the inherent biological reduction in molting as size increases.

No closed systems have been utilized in commercial production. Areas are available for shoreside facilities with good water quality and only flow-through systems or in-water systems (cars) have been utilized in South Carolina.

LICENSING AND PERMITS

Individuals entering the softshell crab shedding industry are required to obtain city, county and state business licenses and to conform to zoning requirements where applicable.

The South Carolina Wildlife and Marine Resources Department's Regulatory Section requires the appropriate individual land and sell and/or wholesale seafood dealer's license.

Shedding operations must also obtain a $75.00 one year permit renewable July 1. This permit entitles operators to catch, take, or transport peeler crabs or shed peeler crabs for the purpose of obtaining softshell crabs.

Shedders can then obtain, free of charge, Identification Cards to issue to individuals employed by the shedder to catch and transport peeler crabs to the shedding operation.

The Marine Resources Division and department law enforcement officers have the authority to inspect the business premises of shedding operations.

The division has the authority to specify: (1) the area from which peeler crabs may be caught or taken by gear other than crab pots; (2) the types of gear or fishing equipment used to take peeler crabs; (3) catch reporting requirements; (4) boat identification requirements; and (5) any other provisions the division deems necessary to carry out the provisions of this section.

First offense convictions are considered misdemeanors and carry a fine of $200.00 or imprisonment for 30 days. Second-offense convictions allow for permit suspension for 30 days and any boat, equipment and rigging engaged in the taking of peeler crabs under permit suspension will be confiscated and sold upon conviction.

RESEARCH AND EXTENSION ACTIVITIES

In 1977 and 1979 regional workshops of softshell crab production were held in Charleston, SC. Workshops included individuals representing the commercial industry, regulatory agencies, seafood processing specialists, and Extension representatives.

A 3-year project funded by Coastal Plains Regional Commission was conducted by the South Carolina Wildlife and Marine Resources Department from 1979 through 1981. The project's major objectives were: (1) to provide information on peeler crab availability, distribution and abundance; (2) to establish effective and pragmatic techniques for capturing peeler crabs; and (3) to demonstrate a shedding operation in South Carolina.

Results of the project were: (1) peelers are available in commercial quantities but are not concentrated in any areas; (2) brushlines did not work for collecting peelers; (3) pounds worked, but tidal amplitude made them impractical; (4) peeler pots worked well for the spring run; (5) habitat pots made of plastic strips weaved through pot mesh captured both male and female peelers, and catch was consistent but low in numbers; and (6) crabs can be

shed in South Carolina successfully with good survival. Marine Extension work has been directed towards individual technical assistance. Spread sheet analysis of shedding operations has been conducted for interested individuals.

CURRENT PROBLEMS AND RESEARCH NEEDS

A meeting of shedding operators in South Carolina was held in December 1984, and the problems and research needs voiced by industry were: (1) South Carolina crabbers as a group have not maintained as high an image in the commercial fishing community as their counterparts in such states as Virginia and Maryland; (2) peeler supply to shedding operations is the major problem in maintaining a sustained industry in South Carolina; and (3) any research should be directed towards peeler crab harvesting gear taking into account the increased tidal amplitude and lack of eelgrass in South Carolina.

SOUTH CAROLINA SOFTSHELL CRAB LITERATURE

Bearden, C. M., D. M. Cupka, C. H. Farmer, III, J. D. Whitaker, and S. Hopkins. 1979. Information on establishing a soft shell crab operation in South Carolina. Office of Conservation, Management, and Marketing, South Carolina Wildlife and Marine Resources Dept., Charleston, SC.

Bishop, J. M., E. J. Olmi, III and J. D. Whitaker. 1982. South Carolina's soft-shell crab program. Perry, H. M. and W. A. Van Engel, eds. *Proceedings of the Blue Crab Colloquium.* 1979 October 16–19; Biloxi, MS. Gulf States Marine Fisheries Commission 7:159–165.

_____ , and G. M. Yianopoulos. 1983. Capture of blue crab peelers in South Carolina: an analysis of techniques. *Trans. Am. Fish. Soc.* 112:60–70.

Bishop, J. M., E. J. Olmi, III, and G. M. Yianopoulos. 1984. Efficacy of peeler pots and experimental habitat pots for capture of pre molt blue crabs. *Trans. Am. Fish. Soc.* 113:642–654.

Cupka, D. M. and W. A. Van Engel. 1980. *Proc. Workshop on Soft Shell Blue Crabs.* South Carolina Wildlife and Marine Resources Center Tech. Rep. 48.

Rhodes, R. J. and W. A. Van Engel, eds. 1978. *Report of the National Blue Crab Industry Workshop.* South Carolina Wildlife and Marine Resources Dept., special report from the South Carolina Marine Resources Center, Charleston, SC.

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SOFT SHELL CRAB FISHERY IN GEORGIA

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Prior to 1970, commercial soft crab production in Georgia was virtually nonexistent. The first successful shedding facility was established on Wilmington Island near Savannah in 1970. This was a flow-through system with a shallow well pump supplying water to 12 tanks which were made of concrete block.

The success of this facility created interest in soft crabs, but problems such as the cost of waterfront property, labor, high summertime water temperature, and inability to maintain a steady supply of peelers soon discouraged most crab fishermen. Two hard crab processing plants tried shedding crabs in the mid-1970's, but similar problems caused them to abandon the project.

In 1981, Marine Extension staff members set up a closed system at a local crabber's house in Brunswick. This system was an improvement over the flow-through system, because it let the crabber move the system away from high-cost waterfront property and close to home for ease of checking the peelers.

Because maintaining a steady supply of quality peelers is the key to having a successful shedding operation, Marine Extension staff members have directed considerable effort towards more productive harvesting techniques. We have tried scrapes, bushlines, and peeler pots with little or no success. Methods used in the Gulf and Chesapeake Bay do not work very well in Georgia where 6- to 9-foot tides are common.

In 1981, Marine Extension staff members conducted a study comparing seven different trap designs. Four were habitat traps, a Chesapeake peeler pot, and a standard hard crab trap. Trap 1 was a reduced habitat trap, 2 ft X 2 ft X 14 inches, with two throats, no baffle, no baitwell, and was constructed of 1.5-inch vinyl-coated crab pot wire. This trap had artificial "grass" tied in the bottom. The artificial grass was polypropylene string used in the manufacture of indoor/outdoor carpeting. Trap 2 was a habitat tray, 2 ft X 2 ft X 4 inches, constructed of 1-inch vinyl-coated baitwell wire with artificial grass tied in the bottom; one-quarter-inch line was tied at each corner and connected to form a four-point bridle. Trap 3 was a Maryland habitat pot which is the standard pot used to catch peelers in the Chesapeake Bay area. It was made of 1-inch galvanized baitwell wire. Trap 4 was a peeler pot, 2 ft X 2 ft X 17 inches, made of 1-inch baitwell wire with four throats, a baffle, and a compartment replacing the baitwell to hold 2 to 4 mature male crabs. Trap 5 was a standard, 2 ft X 2 ft X 17-inch, crab trap with two throats, a baffle, and baitwell. It was made of 1.5-inch vinyl-coated crab pot wire with strips of visqueen woven through the meshes on all four sides. Traps 6 and 7 were standard 2 ft X 2 ft X 17-inch hard crab pots made of 1.5-inch galvanized pot wire. One was used unbaited and the other was baited with Atlantic menhaden (*Brevoortia tyrannus*). All habitat traps were fished unbaited. The peeler pot was baited with two adult male crabs.

Results showed the reduced habitat trap to be the best producer of ripe peelers. The standard baited trap caught more peelers, but most were white line and it was not feasible to hold them.

Requests for assistance in starting new shedding facilities increased each year. We have assisted in setting up four new systems in the past 3 years, and have helped solve problems in several established facilities.

A closed recirculating system, with a protein skimmer, is being set up at the Brunswick lab. When completed it will have ten 3 X 8 X 1-foot fiberglass tanks housed in a 20- X 30-foot building. Possible projects at the facility include using different types of filter material and holding white line peelers until they shed. Chesapeake Bay shedders already do this with some success. We have about a 10 to 1 ratio of white-to-ripe peelers caught in our hard crab pot and need to find a way to take advantage of their abundance.

In the past, nearly all of the soft crabs produced in Georgia have been shipped out of state. We plan to work with local retail seafood dealers and restaurants to promote soft crabs locally.

Shedders in Georgia produced over 22,000 pounds of soft crabs in 1984, valued at over $28,000.

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STATUS OF THE FLORIDA SOFT CRAB FISHERY

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HISTORICAL PRODUCTION AND VALUE

The Florida soft crab fishery is relatively young when compared to the Chesapeake Bay fishery. Soft-shell blue crab production had been attempted many times in Florida, but few operations were successful and virtually none continued for more than a couple of years. A true commercial fishery for soft crabs did not begin until the mid-1950's following an experimental shedding project at Punta Gorda, FL, in 1953 (Young 1955). However, commercial operations in Florida did not generate any significant production until the 1960's. At that time, shedding operations were centered in southwestern Florida (Charlotte Harbor) and in the Panhandle (Apalachicola Bay).

Historically, production has varied drastically from year to year with an extreme slump period from 1968 to 1977 (Table 1). Since 1978, there has been a marked increase in production, with a record of 53,567 pounds reported in 1982 (National Marine Fisheries Service [NMFS] statistics). Production averages for the 1960's, 197C's and 1980's were 5,169, 3,645 and 30,863 pounds per year, respectively.

During the period from 1960 to 1982, exvessel price averaged $0.65 per pound (Table 1). However, in 1983 the exvessel price jumped to $2.22 per pound, with a small decline in production. This trend continued into 1984. The total exvessel value of this fishery in 1983 was reported to be nearly $80,000 (NMFS statistics). Unfortunately, the reported exvessel value combined the price paid to crabbers for premolt (peeler) crabs as well as the price received by those crabbers that produced the actual soft crab product before selling. For that reason, the inflated price per pound in recent years may only reflect that more crabbers are shedding crabs before selling them.

SEA GRANT EXTENSION ACTIVITIES

Florida Sea Grant involvement with the soft crab fishery began in 1978 with basic advisory service consultations and an intensive review of the literature and fishery as it existed nationwide (Otwell and Cato 1982). Early clientele interest was focused primarily in the St. John's River (northeastern Florida) and the Crystal River (central gulf coast) areas. This interest initiated a demonstration shedding project at Palatka, FL, using floats in the St. John's River during 1979. The demonstration project culminated in several publications and fact sheets (Otwell 1980, Otwell et al. 1980, Otwell et al. 1981), which were disseminated during a series of workshops held around the state from 1980 to 1983. These workshops (14 total) were held in the major blue-crab producing areas, including Apalachicola, Cross City, Crystal River, Punta Gorda, Palatka, and Fernindina Beach, reaching more than 400 interested persons. The number of soft crab shedding operations jumped markedly from one-half dozen in 1978 to near 30 by the end of 1982, resulting in the corresponding increase in production as previously noted. By 1983, Florida had become fifth nationwide in reported production of soft crabs (Table 2).

With the increased interest in soft crabs in Florida, several problem areas became evident that required further attention, in particular, shedding mortality and peeler harvest. To address the mortality issues a closed system demonstration project was started in 1983 at Punta Gorda, FL. Technology utilized in other states, particularly protein skimmers and biological filters, were incorporated to improve water quality in the shedding tanks, thereby decreasing shedding mortality. Preliminary results have been very encouraging and a Sea Grant report will be forthcoming. Consistent supply of peeler crabs has also been a constant problem for this fishery in Florida, and a peeler pound (or bank trap) demonstration project was initiated in 1984 near Ft. Myers to adapt this type of gear to Florida gulf coast habitats. Trap designs were patterned after those used in the Chesapeake Bay fishery, with modifications made to suit the extremely shallow slopes of the estuaries of southwestern Florida. This project is ongoing with a report expected by the end of 1985.

In addition to the demonstration projects, questions concerning the nutritional and microbial attributes of fresh soft crabs were examined, particularly in relation to shelf-life and handling requirements (Otwell and Koburger 1985).

DESCRIPTION OF THE FISHERY: A SURVEY

Florida Sea Grant, having been involved in the development of the Florida soft crab fishery since 1978, decided that an evaluation of the status of this fishery was necessary to determine to what extent Sea Grant Extension activities would be needed to further its development. To that end, this author, in cooperation with Florida Sea Grant marine extension agents and specialists, conducted a survey of the 1983 soft crab producers. Out of 28 identified blue crab shedding operations known to be producing soft shell

TABLE 1.

Total annual landings and value of soft blue crabs in Florida, 1960–1984[1]

Year	Total Pounds (Shedded)	Total Value ($) (Exvessel)	Value/Pound ($) (Exvessel)[2]
1960	4,550	2,275	0.50
1961	5,511	2,756	0.50
1962	375	188	0.50
1963	4,200	2,100	0.50
1964	15,063	7,230	0.48
1965	12,643	9,229	0.73
1966	1,030	288	0.28
1967	7,487	4,717	0.63
1968	325	130	0.40
1969	504	186	0.37
10-yr avg.	**5,169**	**2,910**	**0.49**
1970	451	248	0.55
1971	35	14	0.40
1972	152	147	0.97
1973	0	--	--
1974	281	169	0.60
1975	2,106	1,664	0.79
1976	235	193	0.82
1977	205	242	1.18
1978	23,659	28,368	1.20
1979	9,328	5,031	0.54
10-yr avg.	**3,645**	**3,608**	**0.71**
1980	16,866	12,228	0.73
1981	22,631	14,530	0.64
1982	53,567	51,741	0.97
1983	35,908	79,878	2.22
1984[3]	25,343	70,070	2.76
5-yr avg.	**30,863**	**45,689**	**1.46**

[1]Source:National Marine Fisheries Service, Statistical Department, Southeast Fisheries Center, Miami, FL.
[2]Value computed from reported total value data.
[3]Estimated from partial NMFS statistics

TABLE 2.

Florida soft crab fishery – 1983.

Crab Size	Carapace Width (inches)	Percent
Whales	>5.5	44.0
Jumbos	5.0 – 5.5	34.5
Primes	4.5 – 5.0	11.6
Hotels	4.0 – 4.5	2.5
Mediums	3.5 – 4.0	7.0
Smalls	<3.5	0.3
Fresh		7.0
Frozen		93.0

crabs in 1983, 22 (78.6%) cooperated in filling out a fishery questionnaire which included sections describing their shedding facility, harvesting methods, product types, production and sales data, and production costs. The remainder of this paper will be the findings of that survey.

Shedding Operations

Being a relatively young fishery, the experience level of the Florida producers was low as seen in the average number of years in business (3.75 years). Approximately three persons operate an average shedding facility in Florida and use about 16 wooden table tanks (4 ft × 8 ft × 8 in. box on legs) to hold their premolt crabs (peelers) to await their molt (shedding). Only two shedders interviewed utilized anything other than table tanks, that being cement tanks of varying dimensions. These were not preferred due to their expense in manufacturing and the difficulty experienced in sorting crabs from such systems.

The type of water-flow systems utilized are almost equally distributed among open, flow-through systems (36.4%), completely closed, recirculating systems (31.8%), and semi-closed systems (31.8%). The latter of which are open systems modified to act as a closed system for short periods of time.

Filter systems ranged from none (19%) to high-tech bio-disk filters with protein skimmers. The most common filter was simply some form of physical filtration (screens, foam rubber, spun glass, etc., 66.7%), followed by biological filtration (47.6%). Generally, physical and biological filters were combined (47.6%). Other forms of filtration used were protein skimmers (9.5%) and algal filters (9.5%).

Harvesting Methods

In general, 3 to 4 crabbers supplied peeler crabs to each shedding facility (mean, 3.45). Florida's peeler crab fishery has remained primarily a nondirected fishery with 85% of the soft crab operations acquiring some or all of their peelers incidental to traditional blue crab catch, using standard blue crab traps. However, many crabbers were beginning to use directed gear, such as peeler traps [baited with large male crabs (jimmies) or unbaited] and peeler pounds (bank traps). It was common to find a combination of trapping methods being used (70% of the operations), because most producers had trouble getting enough peelers to shed and needed to acquire them in as many ways as possible. In most cases, the operations that produced soft crabs consistently were ones in which the operator directly fished for peeler crabs.

The season for peeler crab harvest in Florida, as in other states, is controlled by environmental and biological parameters rather than by regulation. Generally, the season begins by mid-March, with a 4- to 6-week peak in April and May. A summer lull period occurs in July and August, followed by a short fall peak in September. One soft crab shedding facility did continue operations throughout the year in 1983, but most shutdown by the end of October.

Product Types

Six size grades of soft crabs are produced in Florida.

Almost 80% of the product is in the largest two size classes, whales and jumbos (Table 2). The other grades are primes, hotels, mediums and smalls.

The bulk of Florida's soft crabs were marketed frozen (93%). The remaining fresh product (7%) was marketed early in the season prior to the onset of the Chesapeake Bay run (generally by mid-May) and/or to local restaurants and retail seafood markets.

Production

The majority of the soft crabs were produced on the western coast of Florida, with the Big Bend region from Apalachicola to Cedar Key accounting for 45.4% of the 1983 production (48,070 lbs, Figure 1). Based on the survey results, the total soft crab production in Florida for 1983 was 105,969 pounds. This value is almost three times the reported production of 35,908 pounds according to NMFS statistics (Table 3). This was expected because a large percentage of Florida's production is from small-scale backyard operations run by individual crabbers. These operations are difficult to identify and to obtain data from by NMFS port agents. Nevertheless, the survey results do indicate that the soft crab fishery in Florida is much larger than previously estimated.

TABLE 3.

Reported U.S. soft crab production, 1983.

State	Pounds	Percent
Maryland	3,525,591	79.7
Virginia	657,847	14.9
Louisiana	101,497	2.3
North Carolina	87,570	2.0
Florida	35,908	0.8
Georgia	11,251	0.3
South Carolina	3,691	0.1
Combined Alabama, Mississippi, Texas, and Delaware	0	
Total	4,423,355	

Economics

Soft crabs are sold by the dozen in Florida, as is the case in most states. Prices received per dozen varied throughout the year, depending upon supply and size. Average price-per-dozen ranged from $7.00 per dozen for smalls to a high of $24.00 per dozen for whales. Taking into account the number of dozen produced in each size class, the average price-per-dozen received overall was $13.93 (approximately $4.64 per pound), with total Florida sales at the wholesale level reaching nearly $476,000 in 1983.

Expenditures to operate the facility included rent or mortagage, electricity, labor, supplies and miscellaneous. These expenses average $275.00 per month.

Future Development Needs

Three areas of need were commonly pointed out by soft crab producers during the survey. These were: (1) maintaining a consistent supply of peelers, (2) reducing shedding mortality, and (3) improving marketing. As stated earlier, Florida Sea Grant has begun to address mortality and peeler supply issues, although published information is not yet available. Technology and information from other soft crab-producing states has been distributed to producers upon request or during individual consultations to assist them with problems of these kinds. Concerning marketing, Florida Sea Grant has not taken an active role, leaving this area up to the industry itself and the Florida Department of Natural Resources, Bureau of Marketing and Extension. However, to educate potential buyers as to where soft crabs may be found in Florida, a soft crab producers list for Florida has been published since 1982 and is available from the Florida Sea Grant Extension Program.

Future Sea Grant involvement in this fishery will be devoted mainly to advisory services and individual consultations to improve efficiency of the already existing operations and encourage directed effort to the harvest of peeler crabs. Any future workshops would be focused on these specific topics. In addition, a possible in-depth economic analysis of this fishery has been discussed as a future project.

REFERENCES CITED

Otwell, W. Steven. 1980. Harvest and identification of peeler crabs. Florida Sea Grant Publication MAFS–26, 4 p.

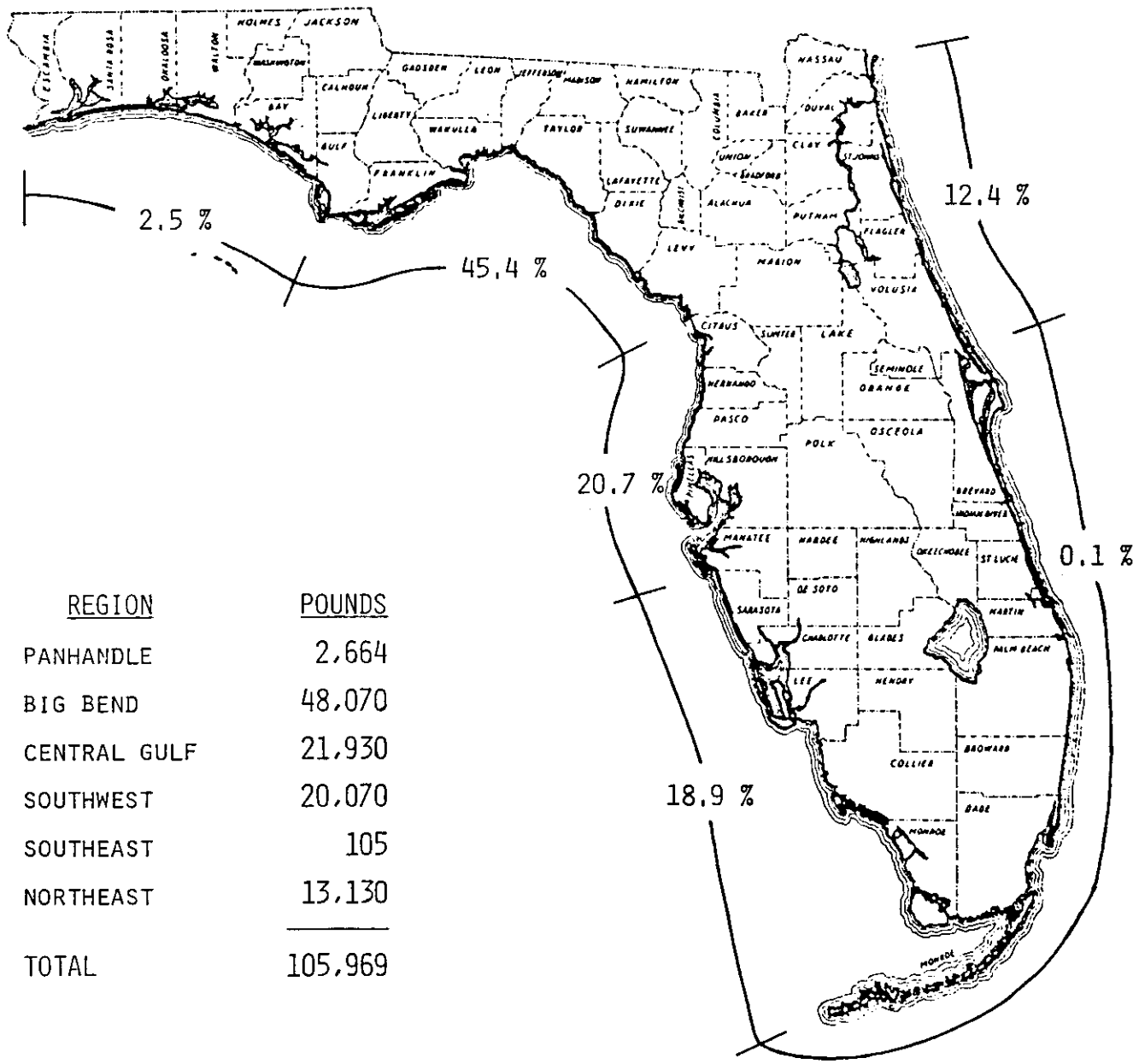
_____ , James C. Cato and Joseph G. Halusky. 1980. Development of a soft crab fishery in Florida. Florida Sea Grant Report No. 31, 55 p.

Otwell, W. Steven, John Stevely and Don Sweat. 1981. Fish facts for Florida consumers: Soft crab. Florida Sea Grant Publication MAFS–33, 6 p.

Otwell, W. Steven and James C. Cato. 1982. Review of the soft-shell crab fishery in the United States. Perry, H. M. and W. A. Van Engel, eds. *Proceedings of the Blue Crab Colloquium.* 1979 October 16–29; Biloxi, MS. Gulf States Marine Fisheries Commission. 7:129–136.

Otwell, W. Steven and Jack Koburger. 1985. Nutritional and microbial attributes of soft crabs. Perry, H. M., ed. *Proc. National Symposium on the Soft-Shelled Blue Crab Fishery,* 1985 February 12–13, Biloxi, MS. Available from Mississippi-Alabama Sea Grant Consortium, Ocean Springs, MS. 77–79.

Young, R. H. 1955. How to set up a soft crab plant in Florida. University of Miami, Special Serv. Bull., 11:5 p.



REGION	POUNDS
PANHANDLE	2,664
BIG BEND	48,070
CENTRAL GULF	21,930
SOUTHWEST	20,070
SOUTHEAST	105
NORTHEAST	13,130
TOTAL	105,969

Figure 1. Florida soft crab production, 1983.

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985, 100.

SOFT–SHELL CRABS IN ALABAMA

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The soft-shell crab fishery in Alabama is very low keyed and the catch is mostly incidental to hard crab fishing activities. A few crabbers have small flow-through systems or in-water floats to hold a limited number of crabs for shedding. No statistics are kept on soft-shell crab production and the total volume is unknown.

Workshops on producing soft-shell crabs in 1980 and 1981 sponsored by the Alabama Sea Grant Advisory Service, with the help of the Alabama Department of Conservation and Natural Resources, Marine Resource Division and Harriet Perry of the Gulf Coast Research Laboratory (Ocean Springs, MS), inspired a few interested persons to build closed systems for shedding crabs. Two of these are still active and one may be reactivated in the near future.

Research and workshops, sponsored in part by the Mississippi-Alabama Sea Grant Consortium, in Mississippi and Louisiana during 1983 and 1984, sparked renewed interest for soft-shell crab information in Alabama. This led to two successful Alabama Sea Grant Advisory Service workshops with the help of Louisiana State University researchers and Harriet Perry. A survey of workshop participants indicated that 60% thought they could run a profitable, soft-shell crab business based on the information received at the workshop. Another 21% felt that maybe they could make a profit. Following these workshops, 16 people were interested enough to participate in a Sea Grant Advisory Service-sponsored field trip to see the soft-shell crab operation of Mr. Cultus Pearson in Louisiana. One participant has built a small closed system for the upcoming season and another is considering starting a major operation.

Existing producers and potential producers expressed concerns about monitoring water quality in closed systems. In response, the Alabama Sea Grant Advisory Service obtained water-quality testing equipment to further assist the development of the soft-shell crab industry. The availability of the equipment and personnel have been widely publicized in the fishing community.

Some workshop participants, after further consultation with the Advisory Service, felt that the supply of shedder crabs was too unreliable in Alabama to warrant a major investment. Indeed, with little or no tradition for sorting out peeler crabs and a relatively small crab fishery in the first place, the supply of peeler crabs is the major constraint to developing a large soft-shell crab industry in Alabama.

Despite these problems, the possibility of a small, successful soft-shell crab industry in Alabama remains a reality if the operators can establish good working relationships with existing crabbers or train new ones to provide a reliable supply of peeler crabs. The Alabama Sea Grant Advisory Service will continue to aid the development of the industry through workshops, publications, water-quality testing, and individual consultations.

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985, 101.

SOFT SHELLED CRAB ACTIVITY: MISSISSIPPI

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As in other states harvesting the blue crab, traditional methods of shedding became less successful as coastal water quality declined. In the Gulf of Mexico, where crab fishermen are often limited by the availability of peelers, commercial viability is dependent on a high ratio of shedding success.

In 1974, concerted efforts began in Mississippi to develop a closed, recirculating-seawater system in which to shed crabs. The initial research was conducted by Harriet Perry, of the Gulf Coast Research Laboratory (GCRL), Ocean Springs, and Mr. Lee Seymour, a commercial crab shedder of Biloxi, MS. This was the first effort, to my knowledge, to develop a closed, commercial-scale recirculation system for holding and shedding crabs. By 1979, Seymour had a successful production system in operation which was producing 60- to 90-dozen soft shell crabs per day.

In the late 1970's, Perry, along with Larry Nicholson and John Ogle, both of GCRL, began working with Mr. Cultus Pearson of Lacombe, LA. Pearson is a commercial crab fisherman who at that time was shedding crabs in an open system and also using holding pens in Lake Pontchartrain, LA. During the next two years, Pearson, Perry, Nicholson, and Ogle designed and implemented a closed, recirculating system that operated successfully for several years. Recognizing the potential value of and the tremendous interest in this fishery, the Sea Grant programs of Mississippi, Alabama and Louisiana began a multi-agency multidisciplinary project to establish production levels and operating parameters for closed systems currently in use in the fishery, and to investigate design changes to increase filter efficiency and carrying capacity. As a result of the 1982–83 effort, management guidelines for operating closed systems were developed and engineering-design changes increased filter efficiency with a subsequent increase in carrying capacity.

In 1984, the Louisiana effort was directed toward filter design, with research in Mississippi looking into the effects of ammonia and nitrite accumulations on blue crab shedding success. Funding of this project by the Mississippi-Alabama Sea Grant Consortium (MASGC) provided the engineers with data necessary to design a more efficient, economical filtration system. The development of these closed, commercial-scale, recirculating-seawater systems to hold and shed peeler crabs allowed for expansion on the industry independent of coastal water quality. Thus, the supply of peeler crabs became the major limiting factor in the growth of the fishery along the Gulf.

With this in mind, research efforts turned to development of technology to provide a consistent supply of peelers. A project conducted by GCRL with the support of the Mississippi Bureau of Marine Resources reviewed all available literature concerning systems design in an effort to develop a closed, recirculating system in which to hold intermolt blue crabs until shedding signs were visible. A publication from that study is now available entitled, *Closed Recirculating Seawater Systems for Holding Intermolt Blue Crabs: Literature Review, Systems Design, and Construction.*

In a study recently funded by the Mississippi-Alabama Sea Grant Consortium, Harriet Perry (GCRL) and Dr. John Freeman of the University of South Alabama will be studying the use of 20-hydroxyecdysone to initiate pro-ecdysis in intermolt blue crabs. If a commercially acceptable technique to initiate pro-ecdysis is developed, it would assure a more constant supply of peelers to the soft-shelled crab producer.

With continued cooperative efforts, such as those described above, the soft-shell crab industry has the potential of becoming a valuable fishery in both the Gulf and Atlantic states.

Although Mississippi presently does not support a major soft-crab fishery, the early research efforts and ultimate success of the closed, recirculating-seawater system for shedding crabs developed in this state have done much to move the industry forward.

The Mississippi Cooperative Extension Service, Marine Advisory Program, continues to work closely with all research agencies to keep abreast of developments in the fishery and to distribute information as it becomes available.

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985, 102–103.

STATUS OF THE LOUISIANA SOFT SHELL CRAB FISHERY

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Louisiana, unlike the other Gulf states, has a long and successful history of commercial soft-shell crab production. Heavy production has been centered in four coastal parishes. Approximately two-thirds of the state's production has historically come from Orleans, St. Tammany and northern Jefferson parishes which border on Lake Pontchartrain. Virtually all of the production from this area is marketed directly by the producer to the final consumer or restaurant. Because the National Marine Fisheries Service collects its landing information from wholesalers, this area's production is almost completely unrecorded.

The remaining one-third of Louisiana's production has, in the past, come from lower Jefferson Parish in the Barataria estuary. Much of this production moves through the hands of wholesalers and crab brokers and has been recorded.

This area, which is the best monitored area of the state for soft-shell crab production, has unfortunately exhibited the least increase in production. The fishery in this area is with bush lines, a method very successful there but no where else. Every crab caught with bush lines sheds within three days and because water quality in the shedding area has not degraded significantly, all the fishermen use float cars. Because the philosophy of the Marine Advisory Service is to promote the *simplest* successful method and to "not fix something if it isn't broken," we have not advocated the use of closed or open circulating systems here.

The areas of the state in which the efforts of the Marine Advisory Service have been most notable are the traditional soft-crab shedding area around Lake Pontchartrain mentioned earlier, and in the south-central portion of the state where soft-crab production has not taken place previously.

The parishes bordering Lake Pontchartrain have increasingly had to rely on medium technology systems (open circulating systems) and even more on high technology closed systems than ever before. The reasons for this change include urban sprawl which eliminates waterfront sites and degrades water quality which, of course, hampers production.

In this area, approximately 50% of the crab shedders have abandoned the use of float cars as their primary means of shedding crabs in the last three years. About one-half of these people use closed systems and the other one-half use open systems. In addition, the number of new crab shedders around Lake Pontchartrain has increased 15 to 20% in the last three years. Virtually, all of these people use closed systems. The technology which has made this possible has its roots in Mr. Cultus Pearson's pioneering work, additional Sea Grant research, and the educational effort of the Marine Extension agents.

Float cars have not been completely abandoned, however, by most users of circulating systems. Some shedders use them to hold their green crabs (white sign) and for emergency overflow when they blow a system up or they catch too many peelers.

Some crabbers have reported a 25% decrease in mortality after switching from float cars to closed systems. Some crabbers have also reported real success stories with aeration of their filter beds, a recommendation based on research conducted by Dr. Ron Malone of Louisiana State University.

The other area of the state where the Marine Advisory Service has impacted the development of the soft-shell crab industry is the central portion: Lafourche, Terrebonne, St. Charles, and St. Mary parishes, where commercial soft-shell crab production has never before occurred. Here, not only have some crabbers begun shedding crabs, but crabmeat factories have begun grading their hard crab catch for peelers. Almost all of these shedders use closed systems. The mortality rate is, of course, higher for crabs graded and shed at crab factories, but it has proven to be economically feasible.

One final method of crab production which is beginning to take hold is the shedding of crabs onboard shrimp vessels in open-recirculating systems. A shrimp boat can easily produce $500 worth of soft-shell crabs during a one-week shrimping trip.

The Marine Advisory Service has taken both a one-on-one and a mass-education approach in disseminating shedding technology information to users. Each May for the past two years, we, in conjunction with the Mississippi-Alabama Sea Grant Consortium and the Gulf Coast Research Laboratory (Ocean Springs, MS) have sponsored a soft-shell crab shedding workshop in Lacombe, LA. Attendance has been over 300 people each year. Current plans are to continue this program. In addition each of the 10 extension agents in the state provides hands-on assistance in constructing crab shedding systems for fishermen.

The Louisiana Sea Grant Program in conjunction with the Mississippi-Alabama Sea Grant Consortium has funded and is continuing to fund practical research projects at Louisiana State University. Research has included improving the efficiency of biological filters, alkalinity and salinity parameters, and microcomputer monitoring systems.

Research projects this year will be to examine salinity, temperature and light parameters in conjunction with hormone treatments to accelerate or synchronize shedding and the manipulation of physical parameters alone to synchronize shedding.

Another effort will involve the construction and operation of three closed systems built at 8% scale as demonstration units to be placed in high schools in coastal parishes. The purpose of this effort is to expose the technology of the system to young people who may be entering the fishery after high school.

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985, 104.

SOFT–SHELL CRAB FISHERY IN TEXAS

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Description or definition. Is there a significant difference? To describe the industry requires the use of the negative of activity, i.e., torpidity, comatose, hebetude, inappetency and stupor.

To define the industry requires the opposite of existence, i.e., nonexistent, null, void, or nil but not defunct, absent, lost or exhausted, which implies previous life.

Prior to the 1980's, the preceding statements are substantially accurate. Crab shedding in Texas was left to nature and the crabs. Any crab so unfortunate to shed while in the confines of a pot was summarily cannibalized which explained the excess carapaces (and the cursing crabber cried, "Why do they always eat the big ones?"). Shrimp fishermen found limp delicacies in their trawls and promptly placed them on ice for future consumption. Any soft crab on the menu was supplied from the east coast and most probably from Crisfield, MD.

Commercially, nothing was going on. In the 1960's and early 1970's, Star Crab Company of Palacios, TX, shed a few crabs. Whether or not these were marketed or consumed on the premise is a question. Some soft crab statistics are listed for Texas in *A Profile of the Blue Crab Fishery of the Gulf of Mexico* (Gulf States Marine Fisheries Commission 1982). These are insignificant at best. No statistics are recorded for Texas in the *Proceedings of the Blue Crab Colloquium* (Gulf States Marine Fisheries Commission 1982). There is no mention of soft crabs in *A Contribution to the Biology of the Blue Crab in Texas, with a Description of the Fishery* (William R. More 1969), in *The Future of Texas Fisheries* (Texas Industrial Commission 1975), in *Coastal Fisheries Plan – 1981–82* (Texas Parks and Wildlife Commission 1981), in *Coastal Fisheries Plan – 1984–85* (Texas Parks and Wildlife Commission 1984), in *Monitoring of Texas Coastal Blue Crab Resources – September 1979 – August 1981* (Paul Hammerschmidt 1983), in *Population Trends and Commercial Harvest of the Blue Crab* ***Callinectes sapidus*** *Rathbun, in Texas Bays – September 1978 – August 1979* (Paul Hammerschmidt 1982), or in *Assessment of the Feasibility of Expanding the Blue Crab Fishery in Texas* (Tom Linton).

Impetus to develop an industry in Texas began with the Blue Crab Subcommittee of the Gulf States Marine Fisheries Commission and Harriet M. Perry of the Gulf Coast Research Laboratory (Ocean Springs, MS).

In 1981–82, Don Reynolds, Galveston County, began the construction of a shedding system and in the spring of 1983, produced approximately 500-dozen crabs which were marketed locally.

Eastern coast interests came to Texas in the winter of 1983 and in the spring of 1984 to investigate the potential of buying premolt crabs from hard-crab picking houses. Although a sincere effort was made, the results were discouraging and the Yankees returned home.

In May, 1981, a blue crab workshop was held at Texas A&M University at Galveston, with industry people, commercial crabbers, regulatory personnel from Texas Parks and Wildlife, and Texas Department of Health, Division Shellfish Sanitation Control.

Two years later, demonstration crab-shedding systems were being developed in Port Aransas and Seadrift with Sea Grant money providing some construction material.

The demonstration systems have not been successful. Crabs have been shed, but the supply of premolt crabs remains the problem which has not been solved.

Harvesting gear to provide the demonstration systems with "peelers" is currently being investigated and this spring should see some peculiar contraptions thrashing around the bays or lurking just below the water.

If the dollars are to be made, if the technology transfer takes, if everybody doesn't starve to death first, the next National Symposium may find Texas listed among the soft-shell crab-producing states.

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985, 105–109.

WORKING GROUPS PRESENTATIONS

Harriet Perry and Michael Oesterling, Chairmen

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985, 107.

WORKING GROUPS PRESENTATIONS

INTRODUCTION

MIKE OESTERLING
Virginia Institute of Marine Science

Many times the most useful learning experiences resulting from a conference are not those ideas put forth by the speakers, but are the questions or comments from the attendees. In an effort to tap into the thoughts of everyone attending the Symposium, working groups have been organized. The goals of these groups are to identify information needs of the soft crab industry and to encourage the academic, advisory and management communities to continue research activities within these areas.

Prior to the Symposium individuals from various soft-crab producing states were asked to submit potential questions or topics for discussion (see Appendix 1). Each working group should use these questions as a guide in developing a set of questions that they consider to be the most pressing information gaps.

The working groups will have an hour to an hour and a half to discuss the prepared questions or any other question/topic. A work group leader has been assigned to assist you in developing the top priorities or top needs in either research, advisory services or management. Try to limit your list to approximately five questions. When you return, each group will present their priorities to the whole Symposium. Following the presentations of the working groups, we will begin an open forum where anyone who did not have their questions answered or who wants clarification can address their questions to the Symposium speakers.

(Break into working groups)

(Return from working groups)

Before we begin with the working groups presentations, I would like to make a couple of remarks.

My first comment deals with one of the goals we hoped to accomplish through the working group process and, indeed, the entire Symposium. In the world of applied research funding, many times money is allocated on the basis of "need." One way to identify need is to have industry participants voice concern over particular questions. The publishing of this Symposium will put down for everyone to see the current state of soft shell crab information and the expressed needs of the industry.

Secondly, the question has been raised as to whether this Symposium is going to become an annual affair. That depends on how successful we are in convincing the funding agencies to continue supporting soft crab-oriented research. If there is continued or increased soft crab activity in research or advisory services, and the information being generated is sufficient to warrant an annual meeting, then there will be cause for an annual meeting. At this time, however, we are looking at the possibility of 18 months, 24 months down the road, then assessing the need for a second national symposium on soft crab fisheries. If that happens, you will be notified. In the meantime, keep in touch with your local Sea Grant Marine Advisory Services in the event they sponsor local workshops or seminars on soft crabs.

Group Leader: **C. WAYNE WESCOTT**
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Well, we had quite a nice discussion and we came up with 713 questions, but let me give you 5. We felt that it was important we know the fishing efficiencies of the different peeler-harvesting gears. We also felt that we should try to set up an industry standard for the sizes of soft crabs to ensure quality and we need to determine what that standard should be. We wanted to know if there are any methods that could be used to induce or speed up shedding and syncronization of the shedding process. We wanted to know how physical, chemical, hydrographical, and atmospheric factors influence peeler distribution and movement; in essence, we wanted to know where the peelers are. Finally, how can disease, parasites and metabolic overload be monitored and, more importantly, be prevented? Thank you.

Mike Oesterling: I should have asked you also to tell us how you arrived at your decisions but that's all right.

Group Leader: **KEITH GATES**
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I guess we have six questions and one philosophical statement. I'll start out with the statement first. We talked about the problem and we all realized we needed more peelers. We discussed that issue for about 15 or 20 minutes and finally came to the conclusion that the best way was economic incentive. If the economics were there then the nuts and bolts of the problem would be solved either through education of the crab fisherman, advisory service work or state work.

Now I will list our 6 questions. The first one concerned the optimum conditions onboard the harvesting vessel and during transport, container size, density in container, time out of water, temperature, and moisture. The second question, is there a way to maintain biological filters at a certain level of efficiency when peelers are scarce that would reduce shock-loading problems when peeler abundance increased? Third, we thought that we needed to define basic environmental parameters needed for optimum crab shedding and to develop economically feasible shedding facility designs. The next step would be to develop economically feasible methods of shedding white line crabs. Also important was the initiation of research into crab diseases and cures. Finally, we recognized the need to develop uniform marketing and grading systems for soft shell crabs. That's all I have to report.

Mike Oesterling: We have already heard a couple of repeats and it sounds like people have some similar concerns. Let's go to the next group. An editorial comment on this group; we took editorial license and have nine questions.

Group Leader: **JANIE WAGHORNE**
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Our group as well as selecting questions decided to direct them to appropriate agencies. First, we wanted to know if there was any validity to the contention that peeler harvest will ultimately reduce the hard crab catch? That question is directed to management and research. Are peeler pounds and crab trawls destructive to the resource? Management and research. Third, what are the optimum conditions onboard the harvesting vessel and during transport (container size, density in container, time out of water, temperature, and moisture)? That question is directed to research and industry. In a closed system, how important and efficient are the following for neutralizing waste metabolites: (1) single media biological filter, (2) multimedia biological filter, (3) protein skimmer, (4) algal tank, and (5) supplemental water reservoir. We added the following to that list: fluid bed, biodisc, and sumps. In other words, we are asking, what is the perfect system? That was directed to research and industry. What are the impacts of crab diseases and parasites on soft crab mortality? We added on to that question – what treatments are available? We directed that question to research. What are the current and projected economic analyses of crab shedding operations in different regions of the U.S.? "Where are we going to sell the crabs that we are shedding?" That problem is directed to the Marine Advisory Service. Should more effort and emphasis be put on collecting landings statistics and value of the soft shell crab fishery? How can this be done? That question was directed to management. Our last two were from the miscellaneous list. What effects do moon and tidal stage have on crab shedding and how do weather changes, barometric pressure changes, temperature changes, etc., affect crab shedding? We threw that one up in the air for anyone who would like to answer it. Finally, are there any methods that can be used to induce or speed-up shedding; hormones, temperature manipulation or feeding? We directed that to research.

Mike Oesterling: Last, but not least, John's group.

Group Leader: **JOHN SUPAN**
Marine Extension Agent
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We finally chose 5 questions and I'm going to give you a little bit of the discussion that was brought up around each question. Basically, what we did was try to come up with a question for each category listed. The first one is, can pheromone research be used to increase peeler harvests? We discussed peeler harvesting and quality of peelers and decided that as far as the quality of peelers is concerned, it was just better to leave it up to the businessmen who are buying and selling the peelers. Those fishermen that do not know how to take care of them, just won't get the sales; their's just don't get bought. We decided to just let the business practices take care of that problem. Now, the second question is, how can winter crabs be acclimated or induced to shed using various parameters, other than hormones, such as tank color, light intensity or changing the photoperiod? Third, what causes physical stress prior to and during shedding, what are the effects of temperature on disease and peeler time out of the water, etc.? The fourth question, can a cost-effective field diagnostic kit with symptomatic questions be developed to help control mortality? Can a field of experts on pathology be formed to help to answer some of the questions on mortality? Fifth, should anti-rancidity agents and storage parameters be studied to help increase shelflife to help in the promotion of inland markets? Another general comment along the line of marketing, is there a limit to our promotion? Will we get the soft crabbers to a point where we put them in the plight of the American farmers? They are in the stage of high-intensive work and no markets for the products. There was concern that we basically promote them right out of the business, so to speak. Thank you.

Mike Oesterling: I think you saw that there was a common thread going through the discussion groups. People are interested in diseases, peeler harvests, marketing, and some are concerned about management. Now I hope that the people out there that are responsible for doing some of this work heard what was said and can take that back and communicate with some of your people to do these sorts of things. Additionally, the results of the working groups discussions will be published in the proceedings; we want to make sure that the word is out that we need to do some work. And now for the fun part, we will ask Mr. W. A. Van Engel to come up and moderate a panel composed of the speakers we had yesterday. You all know who you are. Please come forward. This is your chance to ask the questions that didn't get addressed in your work groups or that are sticking in your mind from the presentations.

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985, 111–118.

OPEN FORUM

W. A. VAN ENGEL, *Moderator*
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I thought the gist of the discussions yesterday was best carried on without interruption. I think that this was the feeling of the audience. I don't believe anybody wanted to interrupt your presentations. Let's start out with the idea that some of you would like to have one of the panel participants answer a question that you didn't hear correctly, or it wasn't particularly addressed during their talk. So if you would stand and give your question and address it to a particular participant here, let's see what kind of response we might get. Anybody have a question?

Question – John Supan: We talked about this over coffee and to a few other people, but what about the use of air lifts versus water pumps in a closed system?

Answer – Ron Malone: It is my basic impression that the air lift pump is limited in the amount you can lift, vertical distance, so its application is somewhat limited. The main question is whether you buy a water pump or you buy an air compressor. In general, we would recommend the water pump first, just because its more versatile in the systems. A system that is designed strictly with air lifts would have to have very low vertical drops. As Mike Oesterling pointed out in his discussion of foam fractionaters, you can put a venturi into a line and get air virtually anyplace in the systems. But I think the real bottom line is whether you find that your water pump or your air pump is more reliable. It's my impression that water pumps are more reliable.

Question – W. A. Van Engel: May I ask if you also intended for your question to apply to particular parts of the system where you would use air lifts?

Comment – John Supan: I was interested in the comparison of the air lift system versus the water pump system. I was thinking that maybe an air lift system would provide more oxygen in the water rather than being sprayed by a pump. I'm not an engineer; that is the reason I wanted to ask the question.

Question – W. A. Van Engel: I was thinking about your comments, Ron, about the aeration in the filter bed. What was the point you were making when you stated that an air lift or air induction into the filter bed was useful? Does it need oxygen?

Answer – Ron Malone: In the design of the biological filter beds, the use of an airlift pump is entirely appropriate. You are only trying to lift the water a few inches in terms of hydrostatic head and you want to aerate at the same time. However, it is probably more cost effective in many cases to just divert another line off your pump and recirculate the water. It is really a matter of economics. If you have a number of systems and you can afford an investment of an air compressor, I would be inclined to go that way just to give yourself more versatility, but if you have just a few systems, it would be better to utilize one pump to do more than one thing by valve control diversion. There are some problems also you should be aware of with using air stones or air-injection systems of any type in a brackish-water system. You tend to get deposits of minerals where the air comes out and it does create a maintenance problem in some cases.

Comment – Mike Oesterling: I would like to comment on what Ron was saying about shunting water back through the biological filter. We have done that, and have seen some increased efficiency in our biological filter. In the line that picks up water coming out of the biological filter, we put in a little "Y" and a valve and brought a section of the water right back to the biological filter. In a couple of cases that seemed to have increased the efficiency of the filter. Essentially we are re-aerating with water.

Comment – Ron Malone: Using the recirculation, be it by airlift or by water pump, you can increase the carrying capacity almost 200%.

Question – : In these closed systems is there any chance of overloading the system with oxygen and generating gas-bubble disease or that type of problem?

Answer – Ron Malone: I haven't seen any tendency. The only way you could get gas-bubble disease is if you have a very high-pressure system. It may be possible, but I doubt it; even the venturi operate at a very low pressure. So I haven't seen any problem with that. The saturation level of the water is relatively low so you have to have a very high pressure to have problems in this area.

Comment – Charlotte Mangum: I think you would be likely to cause acid-base problems instead of embolism.

Comment – Ron Malone: I would say that aeration in normal amounts actually helps our acid-base problem because we were producing so much CO_2 in this system as a result of the biological activity that you probably need the excess aeration just to get rid of it. I'm saying that as opposed to having a problem with hyperoxia you are more likely to gain benefit from an acid-base perspective

just because you would be stripping out CO_2 from the system.

Comment – Charlotte Mangum: But it may be possible to cause an alkalinity that the crab couldn't tolerate; it would be very unlikely.

Question – Van Engel: I have heard that the death of molting crabs may be related to an embolism-type of situation. Is there a possibility that this does occur? Has anyone done work of that kind?

Answer – Charlotte Mangum: Okay. It is possible, for example, if you drive pure oxygen through sea water you can raise the alkalinity to an extent where it will cause mortality, but it's very unlikely you would do that by air. It's more likely to do that than to cause embolisms.

Question – Van Engel: Has anybody observed the death of crabs in the buster stage and felt that it might have been due to embolism in the particular system? Any evidence that it is so or not so? Any suggestions?

Question – : If crabs die in the buster stage backing out, is there some point at which you can't still save the product by pulling them out the rest of the way and freezing? If the crab dies in the buster stage or is two-thirds of the way out, can you still salvage the product?

Comment – Van Engel: I think this is a common practice. If you can catch the crab in the stage where it is still fresh enough. How much it's done in practice, I don't know, but perhaps George Spence or Murray Bridges might comment. Do you ever peel (without revealing any of your trade secrets), do you ever peel a crab?

Answer – Murray Bridges If the crab is out far enough that we can save the legs and at least one claw, we use it; but if it's half way out most of the time you can't save the legs.

Question – : In your presentation, you referred to calcium in man-made sea water, you used a graph; could you explain it to me again?

Answer – Ron Malone: I believe the graph you are referring to was a plot that showed an increase in calcium levels in a closed circulating system over a period of about 4 months of heavy loading. The graph showed that there was virtually no change for about 2 months, but during the last 2 months the total calcium concentration in the water itself increased by almost a factor of 5 or 6 and it was exponentially increasing. We believe that indicates the dissolution of the limestone in the biological filter as it neutralizes the acid being produced from the decomposition processes. I brought that to your attention because of our concern that such dramatic increases in calcium could ultimately cause problems in the crabs or influence such things as the rate at which they harden and other important parameters. We have observed no detrimental effects from that, but we really haven't had a chance to check it; we just don't know. From an engineering perspective we know why it's happening, but we don't know from a biological perspective what its impact on the crabs is or could be.

Comment – Jim Cameron: We played around with increases in calcium content during the calcification phase after molt and we went up to about 3 times the normal sea water concentration and they calcify a little faster. They would probably harden up a little faster but we didn't see any adverse effect on the crabs. Now we didn't carry out these experiments for a long period of time, but my guess is this would probably not be a serious problem. Of course, anything that accelerates hardening after molt probably is a problem to the industry but, beyond that, I don't think it would be.

Question – : I want to direct this question to Dr. Cameron. This came out of our discussion group and it seems to be a logical follow up to the work that you have done thus far. One of the questions we had was, is there any sort of chemical or hormonal additive that you could put in a closed system that would slow down the calcification after molt? In other words, extend the time that the product is in the soft state.

Anwser – Jim Cameron: As you heard, we tried the obvious thing of simply reducing calcium and this just causes too many other problems for the crab; it kills them reasonably quickly. There may be, but the problem is, if you prevent the calcium from moving into the animal from the outside it may still be moving from the blood into the new shell; in which case the internal calcium level is going to plunge and that is what causes the problems that really kill the animals. Proper calcium balance is necessary for muscle contraction, heartbeat and that kind of thing, so I don't really know the answer to your question. I wouldn't be too optimistic. Somebody here mentioned they tried EDTA, for example, to tie up calcium and that also killed the crabs, so I don't know.

Comment – John Freeman: We are working with a few compounds, Steve Sykes and myself, at the University of South Alabama that inhibit calcification in sea urchin embryos, some coccoliths and a number of other systems. They definitely stopped calcification in the systems that we have analyzed, which would take you past the 24-hour period. Right now we don't see any big effect on our crustaceans, but we have never tried adding them during molt to see if they could get in much quicker. In our group we mentioned something about tanning; there are compounds that affect tanning. Whether they could be the type compounds that you would want to put in your system, I don't know, but you can actually stop some of the phenoloxidases that control the tanning process of the parts of the shell. It's a possibility.

Comment – Charlotte Mangum: We injected three known inhibitors of an enzyme known as tyrosinase, which is a tanning promoter and two of them were conclusively negative. They had no effect at all. The third one probably should be reexamined. It is an agent called gentisic acid, however, we had to inject it into the animals and that's labor intensive.

Comment – Van Engel: Murray Bridges, who sheds in almost fresh water, has to examine his crab-shedding tanks at more frequent intervals than, say, someone like George Spence, who is shedding in high-salinity water and who may allow as many as 6 hours or more between examining tanks. Am I correct on that? Okay.

Question – Mike Oesterling: Dr. Mangum, we continually get this question. Is it better to move peelers from low salinity to high salinity or vice versa? Any physiological thoughts on that?

Answer – Charlotte Mangum: Two directly opposing thoughts. One might suppose that because the animal isn't spending the energy at high salinity to osmoregulate that it would be easier to undergo this drastic process. I don't think we know that. One might also suppose, on the other hand, that it is easier to undergo the process at low salinity because you can swell more easily by simply passively changing your permeability rather than actively changing it. Does Dr. Cameron have any further points? I think we don't know. There are reasons why either might be easy or neither.

Question – Van Engel: I would like to ask a question of Dr. Johnson about viruses. Although she and I have talked about this before, I don't know that the benefit of her comments has reached any of you. If any of you had a disease organism that you suspected of being viral and she agreed to look at it, how should the tissue be preserved?

Answer – Phyllis Johnson: This is where we get into one of the questions that our group brought up, and that is, some sort of simple diagnostic kit. To send preserved material means that you would have to have some kind of fixative. It doesn't cost very much but it means you've got to have it. Maybe the simpliest thing is to have a sheet of paper with a number of questions that you ask about the system. Number one, is the water quality okay? There is no pathologist that is going to be able to help you with that; and then a number of other questions, things that you could easily do yourself to try not to pinpoint perhaps, but get a general area of where the disease was. If it were bacterial, there are certain things that I could suggest that you could do to determine whether or not it probably was bacterial. There are other things that I could suggest you could do to determine whether or not it possibly is viral. You could do all of those things – give me a telephone call – we could discuss it and then work out whether or not some material needed to be sent to me. I understand the amount of money it takes to do the things that we in the U.S. Government do. We don't think about how much formaldehyde costs, for example, or how easy it is to get. This fixative is something that you would simply have to have on hand along with a couple of pairs of tweezers, some small scissors, a small knife or scapel, and a supply of any kind of screw-capped jars that would not break in the mail.

Question – Van Engel: Would you comment on the size of tissue necessary for examination?

Answer – Phyllis Johnson: You have to use small pieces of tissue. I would have to send a diagram telling you what general tissues you would have to take. I wouldn't expect everybody to know the exact anatomy of the crab but there are certain parts that are very important to diagnosis and it's fairly simple to tell you which parts you should cut out with your little pair of scissors.

Comment – John Supan: I think the advisory service would be able to check water quality. We could cull out a lot of questions from fishermen by checking the quality of the water first and then, as agents, we might be able to use such a diagnostic kit to really determine whether it would be important enough for you to spend your time on such a matter, rather than having 90 or so fishermen calling you once a week thinking that something is wrong with their crabs when it's a problem with their system.

Comment – Richard Wallace: The advisory service could probably come up with some formaldehyde if we had to.

Question – : Evidence was presented yesterday that blue crabs harbor potentially virulent bacteria, and from a human standpoint, should peelers be subject to the same harvesting restrictions that apply to oyster beds and clam beds and other contaiminated areas?

Question – Van Engel: Would anybody on the panel care to answer that loaded question? How about somebody in the advisory services? Bill DuPaul?

Answer – Bill DuPaul: There is nothing to worry about.

Comment – John Hochheimer: I had that concern so I talked to the health department in Maryland and they don't seem too concerned about it because the crab is cooked. As long as you don't mix your cooked crabs and uncooked crabs and that kind of a thing, it's not too big of a deal. The bacteria that you are working with are fairly easily killed by cooking; that pretty much takes care of any bacterial problems.

Question – : I have a question about cholera and other pathogenic problems. This is a developing fishery that could get a black eye quite easily. I remember two, three, four years ago we had a problem of a cholera outbreak in some crabs down in southern Louisiana and it really caused some problems until they got it under control. It was a real scare and I guess some south Louisiana crabbers and processors took a black eye for 6 months or so trying to get people convinced their product was healthy and saleable again. I think that could be a problem. Whether the health department needs to jump on this thing . . . I'm not sure that's the answer, but . . . .

Question – Van Engel: May I ask if anybody knows the resolution to that? Was it a cholera situation and caused from eating crab products? My understanding was that it was due to improperly cooked crabs, undercooked crab meat.

Comment – Charlotte Mangum: Yes, they were improperly cooked by the people who bought them. They were

improperly cooked by any processors. That's like cooking pork so that you don't get trichinosis. If you don't cook your pork properly in the United States you do have a chance of getting trichinosis. People that eat crabs need to know that they have got to cook them properly.

Comment – Harriet Perry: I think they found that the cholera outbreak was caused by mixing cooked and raw crabs in the same container. They cooked the crabs and put them back into the container they had taken the raw crabs from. It was just improper handling.

Comment – Charlotte Mangum: That happened with *Vibrio parahaemolyticus* in Chesapeake Bay, by the way, and I think that the fact that it happened and it was publicized means that people don't do that anymore. The people who live around there know that you just don't do that.

Question – Van Engel: I'd like to ask a question of Dr. Freeman. There has been a long, long history of trying to speed up the molting process by removal of eye stalks. Do you have any personal views as to why eyestalk removal causes high mortality or what are we missing?

Answer – John Freeman: Well, when you take the eye stalks off you are essentially removing a gland that has a similar secretory capacity as the pituitary. It is a physiological shock to the animal and so a number of physiological processes are disturbed; water balance, in addition to the molting rate. So that's one problem. Other problems are infection and bleeding. We have routinely removed the eye stalks from a number of crustaceans and had very good viability but that took time and training, and it was done on a very careful basis. In addition to the mortality from eyestalk removal, you accelerate the molting a little bit but not necessarily enough to make it a viable use in a closed culture system. Use of ecdysone to stimulate molting is a more viable alternative.

Ecdysone has been used successfully. You can, in fact, induce a precocious molt by hormonal injection and that's true for almost all crustaceans. The problem is, how do you get this to a form that is easily used in the shedding facilities? How do you get this to be cost-effective? How do you train the people to do this and what's the best way of going about delivering the hormone to the animal? Those are questions which we are trying to solve. The fact that they will actually take place is very true, but getting it to work on a sound economic basis is what has to be done.

Question – Van Engel: Has this information been published? Are the problems associated with eyestalk removal known sufficiently? Most people have heard about the possibilities but never the results.

Answer – John Freeman: Most of the experiments which have been done on this have been published in scientific literature. I'm not sure it has ever moved into a nonscientific form.

Comment – Van Engel: I think it might be a good little advisory service note to get it spread around to ease some peoples' thoughts about increasing shedding speed and percentage of shedding using eyestalk removal.

Question – Van Engel: I have a question I would like to ask Dr. Mangum. In situations where the sediment is suspended in the water column, is there a problem that can develop in getting adequate respiration across the gill membrane? You know, after a northeast storm in the Chesapeake region, we get a lot of sediments stirred up and crabs sort of "hole up" for a few days. Mortality is often pretty high. Is a film of sediment on the gill or any other kind of covering of the gill, parasites or whatever, detrimental? How bad does a film of sediment on the gill or parasitic infection have to be before they effectively reduce respiration?

Answer – Charlotte Mangum: Mike Oesterling told me yesterday that he had observed branchial chambers stuffed with sediment or silt. I have never observed this and I can't tell you how bad it would have to be. The ventilation rate is very high and I don't really know at what point it would fail. The barnacle parasites, in some species, such as the Alaskan king crab, can get bad enough to inhibit gas exchange.

Comment – Van Engel: There are other animal parasites of the gill chamber. There is a nemertean, *Carcinonemertes carcinophila,* which really infests the gill quite heavily and it takes up the space between the gill plates. Have you seen this? It's a very common parasite found on the gills, it's a nemertean and it's in the high-salinity environment. We have it extensively in the lower Chesapeake Bay and near the mouth of the Bay. I don't know if anybody else has seen it – anybody comment – show of hands that might say they have seen this *Carcinonemertes.* Mike in Virginia or Florida? Florida and Gulf Coast? Harriet, you've seen it down here. The other is, of course, the gooseneck barnacle, *Octolasmis muelleri,* which is also a high-salinity parasite in the gill chamber. There are some ciliates which heavily infest the gills. There is bryozoan called *Triticella,* which we find in the gill chamber. I think any of those things could seriously cover the respiratory elements there. Anybody have any other comments they would like to make about forms they might find on the gills or in the branchial chamber?

Question – Harriet Perry: I have a question for Cultus Pearson and it may ultimately be directed to Dr. Mangum. Are you familiar with what they call sunburn crabs from Lake Pontchartrain?

Answer – Cultus Pearson: I'm not familiar with that term at all. If you would tell me what the result is, I might be familiar with that.

Question – Perry: I'm not really sure. I've gotten calls from crabbers who want to know what a sunburn crab is. Most of them have been from around the Irish Bayou area of Lake Pontchartrain. What is it?

Answer – John Supan: Basically, what they are referring to is that a crab simply wasn't taken care of. Wet bushes weren't used or wet burlap wasn't used and they were just

exposed to the sun and heated, and the peeler crab was of poor quality. I can definitely trace mortality to bought peeelers from people who have just not handled them correctly.

Comment – Cultus Pearson: We know that if you give him [crab] a good sun bath that he is not going to shed too well. I mean that is about the worst way you can do him in. Just let the sun shine on him. Dr. Van Engel, may I ask a question or two. This is just from observation, but it appears as though your mortality rate increases with the increase of salinity that the crabs come out of. This is especially true in the warmer months. Now, if my observation is correct, my question is – what causes this and is there anything that you can do to reduce the mortality rate of the crab? Anyone . . .

Comment – Charlotte Mangum: I'm not sure I understand the question. You are saying that if you take a crab out of high-salinity water and high temperature, it will die more quickly than if you took the crab out of low-salinity waters with the same high temperature?

Comment – Cultus Pearson: That's correct. Much quicker.

Comment – Charlotte Mangum: I simply would have to say no. I have not observed it. And it wouldn't be obvious to me why that would be true. Again, Dr. Cameron might have some comment on that.

Question – Van Engel: At one time, Charlotte, you were interested in the possibility of the crabs not getting enough oxygen if the crabs were in high salinity and high temperature in the summer time. Because hot water with high salinity has a relatively lower capacity for holding oxygen, you know it might go down to 4, 4.5, 5, 5.5, normally at, say, temperarutes from 25°C to 30°C, is the higher temperature going to have an effect in depressing the oxygen so low that the crab cannot get enough oxygen to survive?

Answer – Charlotte Mangum: The difference between the oxygen concentration of air-saturated water at 35 ppt and 0 ppt at any temperature is of the order of 20 to 25%. So it's fractionally smaller, but the force driving the oxygen into the animal is not the concentration but the partial pressure which is the same. The answer to that question might be affirmative only if the animal is in low-oxygen water to begin with. So it would deplete the oxygen content of high-salinity water more rapidly than it would deplete the oxygen content of low-salinity water. However, in general, it's the other way around: low-salinity waters tend to be stratified and, therefore, more often contain low-oxygen pockets than higher salinity waters, so for various reasons, your observation surprises me. Again, in general, high temperature is so much more important in terms of presenting a problem to the crab than any salinity that I would just really like to have more information on the details of the temperature. High temperature is a big, big problem to the blue crab.

Question – Cultus Pearson: Well, could it be possible that when the crabs are at high temperature, you get a little bit of drying out in the gills, and that causes some crystalization of the salt water that will just almost stop the transfer of oxygen when he is out of the water? Could that be possible?

Answer – Charlotte Mangum: I've never watched crystal formation on the gills, but, again, I don't think it would form a film that would be a barrier. I don't see physically why that would be true.

Comment – Cultus Pearson: Okay, thank you.

Comment – Charlotte Mangum: Your observation just puzzles me completely.

Question – Van Engel: Would you have any idea what the oxygen content of the water was where you have seen this situation occurring? Could you get a sample of the water for an oxygen analysis to be made the next time it occurred?

Comment – Cultus Pearson: I'm just talking about the area around Venice and Empire and the area down there. They have an awful lot of trouble with crabs in the summer time, in fact, they really can't market them; especially in Venice, because they can't get them anywhere before they are just about spoiled.

Question – : A temperature of 72°F is supposed to be the optimum temperature for crabs to molt. Is there any system anywhere that keeps a constant 72°F?

Question – Van Engel: Does anybody operate a closed-recirculating system with a constant low temperature? Mike, are you aware of such a thing?

Answer – Mike Oesterling: We've seen some good temperature modification with our closed systems by putting the biological filter in the ground and housing the shedding tanks in a building. In some comparative work between a flow-through system and a closed system in the same building, the only difference being that the closed system had the biological filter in the ground, we have seen as much as a 5°F difference between the flow-through system and the closed system. We have seen the closed system staying considerably cooler in August: 78°F as opposed to 86°F in the natural water. That is without any air conditioning. Now, that has turned out to be both a blessing and a little bit of a problem. When we first started doing this, we thought, "Hot dang, we're going to keep the water cooler and the crabs are going to shed better." They shed alright, but now we are seeing that they take longer to shed because the water is cooling them down a little bit. Some of the people that I've been working with are saying, "The water stays cooler, but the crabs that were shedding in three days are now going to take four days." The same crab in the flow-through system will shed in three days.

Comment – Wayne Wescott: In North Carolina, we deal with several systems that have a controlled-temperature atmosphere. They are all fresh-water systems. Some of them are employing the elements that I mentioned earlier this morning to control temperature when it's too cool and they add fresh water when it becomes too warm. They

have a range of between 72°F and 75°F all the time. There are also other more ingenious-type designs using solar heat to do the heating and fresh well-water to do the cooling. Some of them are shedding the soft crabs for sale in this maintained system and others are simply holding peelers which they are marketing at a profit, but it has been very successful. Getting back to what Mr. Pearson said about the crabs dying, we have experienced this in North Carolina at a certain time of the year. It's usually in June, right after the prime run. The peelers will die almost immediately after they are taken out of the water. Some of our crabbers have actually taken floating shedders to where their peeler pots are and placed them in the water, captured the peeler crabs out of the peeler pot, and held them in the floating shedder in an attempt to get them home which was only 15 minutes away. They still died. The hard crabs at the very same time were living in this situation. I'm not a biologist, I don't know the reason we have this problem. These crabs die almost instantly out of the water. We have it in North Carolina – it's not a happy thing to have.

Comment – Mike Oesterling: We have some problems with crabs dying like that too, and we've put it down to stress or a combination of things. There's no work that's been done on this other than some ramblings of some fishermen and myself; trap stress, just physically being held in a confined area, also the stress of the crab going into a molt; he's in a reduced state. We kind of say it "messes with his head" and there is too much stress and all the increased stress of handling – being taken out of the water. I don't know that you can point your finger at one thing and say this is what is killing the crabs. I think it is a combination of a bunch of different stresses.

Question – Van Engel: Can we try to define what is meant by stress or let me ask a little more direct question? Is there such a possibility of hypoglycemia occurring in crabs that are trapped and could this lead to a very quick death? Are they prone to, say, turn over on their backs and die? And if hypoglycemia, low blood sugar, is possible, are there any good techniques, laboratory or field techniques, for determining this?

Answer – Charlotte Mangum: To answer the last part, there are certainly good laboratory techniques. I don't think there are any good field techniques. I would think that if the pots were not checked for 24 hours, it is likely that the crab would go hypoglycemic, at high temperature particularly. Whether that would be lethal or not in 24 hours, I don't know. But it certainly could weaken the crab.

Question – : I was just wondering if any of this could have anything to do with the bottom type that the trap was sitting on, possibly in anaerobic mud or something? In high temperature that layer of water right above anaerobic mud is almost completely deoxygenated and at a higher temperature it is even going to be worse.

Answer – Charlotte Mangum: That would really depend on the water column and the crab would climb up the side of the cage.

Question – Van Engel: I had a question related to bacteria. We've heard about bacteria being on the body of the crab, the vibrios, and in the blood, and in the gut. Is there any sense in possibly giving the crab a sterilizing dip?

Answer – Phyllis Johnson: Well, I'm not a microbiologist but I would say that if you gave a sterilizing dip to a peeler crab, particularly in a recirculating system, I think you would have Food and Drug, the Public Health Service, and everybody else on your head – I may be wrong. I don't know whether it would help or not. According to Dr. Sizemore, he found more correlation with gill bacteria than he did bacteria on the outside and there was some discussion about whether or not enough of the disinfectant or whatever would be bailed past the gills to really do any good. I have no thought on that either.

Comment – : I'm in the seafood industry and we have a product called sodium bisulfite that we dip some of our shrimp products into that kills the oxygen which bacteria feed on. It might be possible to mix 8 ounces with 500 gallons of water. It might be interesting to try to put a crab through that solution for just a matter of a few seconds just to coat him with it and then put him back into the environment – it may work that way.

Comment – Phyllis Johnson: I don't know how long it takes to kill the bacteria with that product. I really can't answer that. I think it would be very dangerous to put an unrinsed crab back into the tank with that product on it.

Comment – Charlotte Mangum: I'd say the same thing. You would probably be killing the crab at the same time you were killing the bacteria.

Question – Van Engel: I have a question of Dr. DuPaul. He has been very successful in getting soft crabs, frozen soft crabs, accepted in the east and west; Europe and Japan. What's happening on the west coast of the United States? Are they adverse to soft crabs? I don't ever hear of anyone saying anything about shipping frozen soft crabs west of the Mississippi.

Answer – Bill DuPaul: I'm sure that marketing efforts are going on in California and on the west coast and, in fact, I would not be at all surprised that there were products being shipped there on a regular basis right now. That is something that private industry is taking care of. I believe a few of the development foundations, when they had sea fairs on the west coast, brought soft crabs to show. I would not be surprised one bit that soft crabs are being shipped to the west coast. To what quantities, I'm sure private industry would have to answer that one.

Comment – John Supan: On that subject, I'm worried about growing pains in the industry. More shrimpers are talking about going to shedding crabs and getting out of the shrimp business. I'm curious as to what kind of growing pains the Chesapeake went through in the early years. Did they have price wars or did they just send them all to New Orleans?

Answer – Bill DuPaul: All I can do is probably relate to more recent history and that any time during the summer when there are an awful lot of crabs around, the price drops. The markets in New York and Baltimore become soft and basically this is when a lot of the processors will freeze their product and hope for a better price at a later date. Naturally, anytime you are dealing with a fresh product on a market, anytime that you saturate that market, your price drops and the key there is to freeze your production and save it for a better price. But I think this happens almost on a yearly basis from time to time depending upon individual market situations. Some of the industry people might want to elaborate on that, but I think it is pretty much of a generalization.

Comment – John Supan: Some of the other agents in other states that run into problems of promoting production to a point exceeding the demand was in other areas. Do you have any problem with that? I guess I'm talking to North Carolina and South Carolina more specifically.

Comment – Bill DuPaul: I'll comment on that. I think what we are dealing with is this; you can develop a lot of different types of markets, whether it be fresh or frozen; export, domestic, west coast, wherever; the more markets that you can develop the more stability of prices you're going to have over the course of the year. I think that's the driving force behind all these marketing efforts. This would lend a degree of stability to the prices of soft crabs throughout the year. We hear all sorts of stories of $18, $22 a dozen crabs in New York when the season first opens and then we hear stories of $3 and $4 a dozen crabs later on in the summer. If you have the capacity to take advantage of say, foreign markets, and you have the capacity to freeze large quantities of crabs, that is the time you want to freeze and that is the time you want to start selling them in another market. So I think as production increases, with all these advisory efforts and research efforts, as industry expands and production increases, hand to hand there is going to be market development and I think the key to that market development should be linked back to keeping prices stable at the fishing level.

Comment – Scott Andree: In Florida that did occur. The producers that were producing a large quantity of crabs early on in the season had to freeze early and filled up their freezers. They decided they couldn't commit any more space to holding soft crabs so they quit. Since that time they have explored other markets, particularly California, and they are shipping crabs to California from Florida and to Kansas City; the midwestern markets. But we sort of leave that up to the industries to handle that part.

Question – Van Engel: I have a comment I would like to address to all the members of the panel and that is – to give some information to the industry as to what kind of modification of their handling practices, their shedding systems, their marketing that you could tell them about that they could put into effect this year. Now I am thinking specifically say of a question I might address to Dr. Freeman about light, the effect of light, darkness on shedding, continuous, intermittent or length of day, such things as light backgrounds, dark backgrounds in shedding tanks. I might think of such a question to ask Dr. Malone about improving one or other specific parts of either an open-flow or recirculating system. Now I'm not asking for a long discussion but perhaps something that could be a short, simple recommendation. Let's start with Ron.

Comment – Ron Malone: I think in the course of my presentation and our earlier discussions I have addressed a lot of things. What I could say to those of you who are commercial operators, in the spring time when the runs are at a peak, when you have more crabs than you can handle, I advise you to do a couple of things. In our current research we are finding that if you put a physical filter, such as a sand filter in your system, you can increase carrying capacity. I understand some people are using spun insulation or glass for a prefilter. If you put that ahead of your biological filter you can increase the carrying capacity on a closed system by approximately 30%. You don't need to do this while the system's within the design capacity, but at peak loading you can get that much further at no additional cost. And the other thing, of course, is that if you just increase the aeration you will probably see immediate benefit in terms of the number of crabs that survive. Our current research is indicating that those two parameters, reducing loading of the filter and active aeration, will both reap you benefits.

Comment – John Freeman: An important factor is the condition of the crab before it gets to your system. I hear more and more about the condition of the crabs from different places and their dying due to poor handling. That seems to be a very important consideration.

Comment – Bill DuPaul: We received many, many questions and calls about exporting soft crabs from all size producers and many people saw this as an answer to their immediate problem. They had too many crabs and they thought that if they could put several boxes of them up and ship them somewhere, they could get a fancy price for them. That is not the case. Exporting does offer some opportunities but it's not for every producer to engage in. It is difficult, it is time-consuming, and it is expensive. And also more importantly, the producer has to have a long-term committment to produce these soft crabs for export. He can't just do this because he has a problem, such as too many in the freezer, and he thinks this is the thing to do. It's a long-term committment. My recommendation to all these people is: find somebody to sell your crabs to, someone that can export; sell to a broker or someone who has some kind of export company, but don't try to do it yourself on a small scale, you'd just be wasting your time and it's a difficult thing to do.

Comment – Jim Cameron: My work starts, I think, at the

point most of these crabs come out of the water; being interested in the calcification process. One thing I did pick up here is that apparently it would be quite useful if there were some way of slowing down or lengthening out the really soft shell state; slowing down the calcification process. I'm afraid we don't have anything to offer right now but it could be that we will in the future.

Comment – Phyllis Johnson: I think anything I said right now would be taken as being frivilous so far as any help with this year's shedding is concerned. I'd hope that by next year we might have something that could help you, so far as diseases are concerned.

Comment – Charlotte Mangum: I think I will underscore the importance of keeping the oxygen levels up whether it be an open or a closed system. I also want to add, particularly in closed systems that might be utilizing low salinity or even fresh water, that almost certainly pH is going to be a very critical problem.

Comment – Van Engel: How would you alter pH?

Comment – Charlotte Mangum: You would have to ask the engineers. I'm simply talking about monitoring it. Be sure that you are in the right range.

Comment – Ron Malone: The systems are designed to maintain pH if you stay within the design capacity. If you don't and you want to use a chemical, I would suggest something along the lines of sodium hydroxide, NAOH, which will leave no residual effects and alters very little as a side effect. You've got to be careful with that because it can be pretty potent if it's high normally. Sodium bicarbonate will effect pH and also affect the alkalinity of your system. You know it will work. Again, when it's gone or utilized, the bicarbonates are gone and you have only sodium as a residual effect for all practical purposes. I would be inclined to go to sodium hydroxide, myself. I understand both have been used.

Comment – Scott Andree: I could add one comment from Steve Otwell's paper that might be of interest to producers. There was some concern over shelflife of the fresh product. Try to maintain the lower temperature values when you're holding your crabs. Below 35°F would be better than 40°F. It would at least maintain longer shelflife in the fresh form because at 6 days you are getting degradation of the product pretty quickly. That also would inhibit growth of *Vibrio parahaemolyticus* in the products so there would not be any public health threat.

Comment – Van Engel: Last call? I'll turn it over to Mike.

Comment – Mike Oesterling: I have the dubious duty of telling everyone it's time to go have a beer. Thank you very much for your attendance. I hope it was worthwhile. Harriet did tell us that we have some more goodies back at the White Oaks. If you need directions go see her. I would like to personally thank everyone on the panel, the speakers, as well as Harriet and Bill Hosking for the local arrangements and the entertainment last night, and most of all, ya'll for coming. Thank you very much. We're done.

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985, 119–122.

APPENDIX 1

POTENTIAL QUESTIONS OR TOPICS FOR WORKING GROUPS DISCUSSION

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985, 121–122.

POTENTIAL QUESTIONS OR TOPICS

QUESTIONS ON PEELER HARVESTING

P 1. What are the relationships between harvesting techniques and the quality of the peelers, successful sheds and mortality?

P 2. For areas that use modified otter trawls to capture peelers, how long should drags be to ensure quality peelers?

P 3. What are the fishing "efficiencies" of the different peeler harvesting gears?

P 4. What effect does peeler pot construction design (e.g., mesh size, number of entrance funnels, size, construction material, and color) have on harvesting?

P 5. When jimmy potting, what are the best numbers of jimmies to use and how should they be placed in the pot?

P 6. When, where, and why are "bare" pots effective?

P 7. In areas of predominately male peelers what type(s) of gear is (are) most effective and its (their) usage?

P 8. In areas of large tidal flows or high currents, what harvesting techniques are effective?

P 9. How do bottom type, water depth, vegetation and hydrographic parameters affect peeler harvest?

P10. Are there directed movements of peelers towards specific areas (e.g., salty to fresh, deep to shallow, clean bottom to cover)?

P11. In what salinity do you find the most abundant populations of female peelers?

P12. There are indications that terminal molt female crabs release a pheromone which elicits courtship behavior in mature males. Do male crabs likewise secrete a pheromone which attracts female peelers? If so, could this be artificially produced for use in peeler pots?

P13. Should there be uniformity between states on peeler size limits?

P14. What are the current regulations regarding the harvest of peeler crabs in the coastal states? Would standard harvesting regulations benefit the industry?

P15. Is there any validity to the contention that peeler harvest will ultimately reduce the hard crab catch?

P16. Is peeler overfishing possible?

P17. Are peeler pounds destructive to the resource?

P18. What are the optimum conditions onboard the harvesting vessel and during transport? Container size? Density in container? Time out of water? Temperature and moisture?

QUESTIONS ON FACILITY DESIGN/WATER QUALITY

F 1. What rule of thumb can be developed to determine optimum peeler capacity for open and closed systems?

F 2. What are the advantages and disadvantages of centrifugal and submersible pumps for use in open and closed shedding systems?

F 3. Should male and female peelers be separated within shedding facilities?

F 4. What environmental parameters are required to assure a successful flow-through shedding system?

F 5. What physical construction practices and designs would assure maximum water turnover and improve oxygenation in open systems?

F 6. What is the best method to prevent fouling in the input and drain lines when using an open system? What is the best way to clean water delivery lines in an open system? Are there any chemicals not toxic to crabs that can be used to assist in the cleaning process?

F 7. Can anything be done to improve water quality of natural water bodies when using flow-through systems? Is there any way to eliminate silt, mud, etc., before they are pumped into shedding tanks?

F 8. How efficient are cooling towers in controlling temperature?

F 9. In closed systems, how important/efficient are the following for neutralizing waste metabolites: single medium biological filter, multi-media biological filter, protein skimmer, algal tank, supplemental water reservoir?

F10. For biological filters, is there a formula to determine the size required for the number of crabs to be held?

F11. In a biological filter, what type of medium is best in terms of buffering capabilities? Oyster shell? Clam shell? Dolomite limestone?

F12. Is there a way to maintain biological filters at a certain level of efficiency when peelers are scarce that would reduce shock loading problems when peeler abundance increased?

F13. Will changing water often in closed systems totally eliminate water quality problems? If so, how often must water be changed?

F14. After a biological filter is conditioned, how does water replacement affect the filter bacteria and filter efficiency?

F15. Can a heated recirculating system be used to shed blue crabs in the winter?

F16. Is there a way to "winterize" a closed system that will maintain a viable filter bed?

QUESTIONS ON MORTALITIES

M 1. What causes the high mortalities associated with

the June shedding?

M 2. Why do peelers caught near the end of "runs" often die in larger numbers in transit to the shedding facility than during the early part of the run? Handling and temperature are essentially the same.

M 3. When buying peelers, is there any way of determining peeler quality?

M 4. Why do a large number of crabs die half way out of the shell?

M 5. Why is mortality higher for male peelers than females?

M 6. Does the feeding of white line peelers reduce their mortality rate?

M 7. What diagnostic techniques or criteria can be used to identify causes of mortality?

M 8. With natural environmental factors, such as turbidity, mud to bury in, and grass for cover, missing in holding systems, is something being overlooked as regards reducing mortalities?

M 9. The use in Texas of the North Carolina method of shedding crabs in "fresh" water resulted in 100% mortality within hours to 3 to 5 days. Green crab survival was only 50%. What's the secret to freshwater shedding? Is it practical?

M10. What means are available to reduce predation and cannibalism among crabs held in shedding systems?

M11. What is the impact of crab diseases and parasites on soft crab mortality?

M12. What are the toxic effects of waste metabolites, including ammonia, nitrite and nitrate, in closed systems?

M13. Would the use of ozonation and ultraviolet light in shedding systems improve water quality and reduce mortality? Are they economical for soft crab production systems?

M14. Within open flow (flow-through) systems, what are the major factors increasing mortality? How can these be remedied?

QUESTIONS ON ECONOMICS AND MARKETING

E 1. Should industry standards be set for sizes of soft crabs?

E 2. Is there any particular size soft crab that is more desirable than the others?

E 3. What are the advantages and disadvantages of marketing the product fresh? Frozen?

E 4. What is the best wrapping and packaging material for frozen soft crabs?

E 5. When freezing crabs, what are the advantages and disadvantages of cleaned (dressed) versus uncleaned soft crabs? Is there a marketing advantage with one type?

E 6. How long can frozen soft crabs be held without quality loss?

E 7. What are the current and projected economic analyses of crab shedding operations in different regions of the U.S.?

E 8. What are the costs of running open and closed systems, including mortalities and shedding rates?

E 9. What is the economic feasibility of producing soft crabs year-round through temperature controlled systems, including the shedding of white line crabs?

E10. Would it be possible to compile a directory of producers?

MISCELLANEOUS QUESTIONS

X 1. What effects do moon and tidal stage have on crab shedding? How do weather changes (barometric pressure changes, temperature changes, etc.) affect crab shedding?

X 2. Are there any methods that could be used to induce or speed-up shedding (e.g., hormones, temperature manipulation, feeding)?

X 3. Could the lengthening of soft shell hardening times through chemical manipulation significantly reduce labor costs?

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985, 123–128.

APPENDIX 2

SYMPOSIUM ATTENDEES

National Symposium on the Soft-Shelled Blue Crab Fishery, February 12–13, 1985, 125–128.

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