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The Effect of Salinity on Particle Filtration Rates of the West African Mangrove Oyster

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Previous studies exploring the potential of developing mangrove oyster fisheries in Ghana have suggested that this approach could provide both financial gain (Obodai and Yankson, 1999a) and nutritional value (Yankson 2004) to the Ghanaian people, supplementing a historically low-protein diet as well as augmenting local economies. However ,information on the basic ecology of the West African mangrove oyster (*Crassostrea tulipa)* is limited. This study aimed to build preliminary knowledge of this species by investigating the precise relationship between environmental salinity and filtration rates The oyster is a euryhaline organism that thrives in the coastal lagoons of the Ghanaian shoreline. Oysters gathered from two types of coastal lagoons (closed and open) were exposed to salinities varying from 0‰ to 35‰ in intervals of ~7‰; filtration rates at each salinity level were measured hourly. The results showed that a significant difference ($p<0.001$) did exist between the filtration rates of oysters collected from the two sites: the ones collected from the closed lagoon had a greater mean filtration rate at all salinity levels in comparison with those from the open lagoon (6.567 ppm/min, closed lagoon; 3.485 ppm/min, open lagoon).This may be due to either an environmental adaptation or a genetic variation promoting increased filtration capacity, and subsequently, could indicate the presence of two distinct subspecies of *C. tulipa*. Regardless, the higher filtration capacity of the closed lagoon population could indicate greater resistance and superior suitability for industrial cultivation in Ghana, and future fishery development work should focus on the *in situ* husbandry of this closed lagoon subtype.

INTRODUCTION

The West African mangrove oyster *(Crassostrea tulipa)* is a tropical, euryhaline organism that thrives at temperatures of 23 – 31°C. In Ghana, it is most commonly found in one of the more than 90 southern coastal lagoons. The oyster has been known to culture well in brackish mangrove swamps and sheltered aquatic areas t 2 to 5 m deep, where it matures in approximately 7 – 9 months (Ansa and Bashir, 2007). In these coastal lagoons, mangrove oysters most frequently attach themselves to the mangrove tree roots or in the absence of such roots, to the rocky substrate of the lagoon bottom.

Two types of coastal lagoons exist in Ghana: those which are open to the ocean year-round, and maintain salinities approximately equal to seawater at about 35‰, and closed lagoons, which are isolated from the sea by a sandbar for most of the year and exposed to seawater during the rainy season. Within closed lagoons, the salinity increases during the dry season, when the lagoon becomes isolated, and decreases during the rainy season, when the lagoon is inundated with rain and seawater (Yankson and Obodai, 1999).

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Prior work on *C. tulipa* in Ghana showed that, when placed in identical conditions, oysters reared in closed lagoons have higher survival rates than their counterparts reared in open lagoons (Kamara, 1982). These differences in endurance could be attributed to differences in salinity and turbidity between the rearing environment of the two lagoon types in the closed ones, conditions fluctuate seasonally, in contrast to the perennially stable open lagoon environment. during the rainy season at the Nakwa Lagoon (the closed lagoon site used in the present study), salinities can drop as low as 0‰, and during the dry season, they may rise to as high as 35‰. Turbidity is generally higher in the Nakwa lagoon as well : over a period of 14 months, Benya Lagoon (the open lagoon site used in the present study) experienced little fluctuation in transparency, with Secchi Disk Transparency values consistently above 50 cm. Oysters transplanted from Nakwa to Benya experienced equivalent or superior survival to the indigenous oysters, but oysters transplanted from Benya to Nakwa had much lower survival rates than the indigenes.This may have been because the open lagoon environmentdid not allow them to adapt to the more variableclosed lagoon conditions (Obodai and Yankson, 1999b).

The goal of this study was to provide preliminary information for the development of an industry based on the West African mangrove oyster (*Crassostrea tulipa)* in Ghana first, by exploring the effect of salinity on the filtration rates of the oyster and second, by identifying differences in filtration rates between two oyster populations on the Ghanaian coast.

Oyster meat is commonly used as a food source in many parts of West Africa (Kamara, 1982, Yankson, 2004), and within Ghana, the oyster plays additional vital roles in local industry: the shells may be used as a source of calcium in poultry and livestock feeds, an ingredient in paint preparations, rough base for footpaths, concrete for building, and for medicinal uses (Obodai and Yankson, 1999a) which has been documented in other parts of West Africa (Kamara, 1982; Ansa and Bashir, 2007).

The development of a Ghanaian fishery based on *C. tulipa* could provide an improved diet with increased protein intake, as well as sustainably augment local economy. The costs of establishing and maintaining oyster fisheries would be minimal, as the oysters can be grown *in situ*, using limited and local resources, passive cultivation methods not time-demanding or opportunity costs. These culture methods divide roughly into two categories: suspended culture (e.g. rack and raft culture, net culture, mangrove root culture, and tray culture), and bottom culture). Studies in Sierra Leone found the most efficient culture method for *C. tulipa* to be the suspended one (raft), wherein strings of empty oyster shells were attached to the rafts to collect spat. This method produced an average 7 cm, 7 g oyster in 7 months (Kamara, 1982). These findings were reported by South American studies, which found significantly higher survival rates in oysters farmed using a raft system (Lodeiros et. al, 2007). This method may also be preferred because it is the least economically costly; the racks and rafts can be built from local materials recycled yearly, as well as the shells.

In addition to offering oysters as a potential export commodity, the establishment of local fisheries could also provide new sources of income for local workers (Obodai and Yankson, 1999a). Explorations of proposed and developed (both formal and informal) mangrove oyster fisheries have already been carried out in West Africa: Nigeria (Ansa and Bashir, 2007) and Sierra Leone (Kamara, 1981) have both been studied. Further studies have been completed in South and Central America, where the fisheries of Brazil (Silva et. al, 2003) and Venezuela (Gil and Morena, 2007) have undergone extensive research. All studies have shown that oyster fisheries can provide strong economic and cultural benefits to coastal tropical communities, and offer a good profit at manageable local costs. The results of our study may similarly provide a number of additional benefits of fishery development. First and foremost, our data will contribute to a general body of knowledge regarding oyster ecology. Second, a clearer understanding of the effects of salinity on filtration can be used to seek and select sites for oyster fishery/hatchery establishments, for oyster and spatfall collection, to predict the effects of oyster transplantation projects for fishery or conservation purposes, to manipulate fishery practices to control or reduce fouling organisms that might possess different salinity tolerances, or establish the optimal conditions under which oysters can be used as bioremediation organisms.

MATERIALS AND METHODS

Oyster Collection

More than 60 oysters were collected over six weeks from two lagoons (Nakwa and Benya) in southern Ghana. Oysters were collected in the late morning from Nakwa Lagoon, and in the afternoon, at low tide, from the Benya Lagoon. Oysters were collected from Benya Lagoon by wading in to cut roots of mangrove trees and retrieve oyster clusters, and oysters were collected from Nakwa Lagoon by diving and handpicking individual oysters on the lagoon bottom .Oysters were collected differently for each study site because the nature of the substrate and lagoon tides limited the accessibility of oysters for collection. At each site, during each oyster sampling, one 3-gallon bucket of seawater and sediment was also collected for later use in the experiments.

Experimental Tank Preparation

Oysters were grouped by size. For each lagoon, six 5.7L water tanks with salinities ranging from 0‰ to 38‰ at intervals of ~7‰ were used.Tank salinities were measured in parts per thousand (‰) with a manually held refractometer placed in the center of the tank. Each tank was labeled and filled with 4L of water with the assigned salinity. Every experimental tank was replicated twice so that each salinity was replicated in a 3-tank group; control tanks were only replicated once (Figure 1). To reach the proper conditions in each tank, we diluted full strength seawater (36‰±1) with freshwater to the desired salinity

After experimental salinities were prepared, we altered turbidity of the tanks by introducing sediment in increments of one (1) mL, until turbidities of all tanks equaled 100 ppm. To ensure particle suspension uniformity, we agitated sediment containers prior to dispensing. We measured tank turbidities in parts per million (ppm) with a manually held digital turbidimeter. Tank salinities were remeasure after turbidity had been altered to ensure that the addition of sediment did not alter salinity.

Oyster Introduction

Six oysters of sizes (4.0 cm±2) were introduced into each tank, spacing them approximately 6 cm apart. With the start point as the moment of oyster introduction, hourly turbidity readings to monitor the rate of particle filtration were taken and rates converted to ppm/min. In order to determine an average rate of particle removal due to sedimentation, turbidity readings were also taken from two control tanks, without oysters

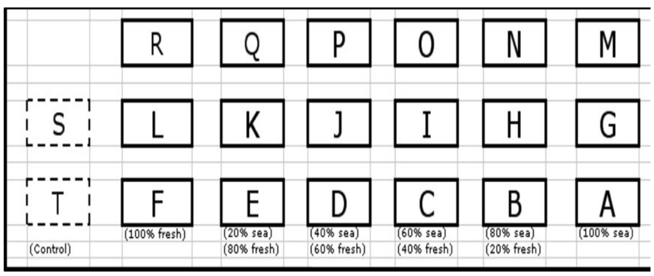

Figure 1. Tank Setup in Laboratory: Tanks were arranged by seawater percentage/salinity – this image presents the tank layout for the experiment. This layout was replicated twice – once for each lagoon.

Statistical Analysis

The Microsoft Excel program was used for statistical analysis. An ANOVA test was run to determine any significant difference between the mean filtration rates of the Nakwa and Benya oysters. A two tailed t-test was then run to determine whether any significant differences existed between filtration rates in varying salinities. The significance level was set to 0.05.

RESULTS

Benya (Open) Lagoon

In the Benya Lagoon oysters, maximum average filtration rates were reached in tanks of 100% and 80% seawater (~34‰, 27‰). Filtration rates in 60% seawater (21.9‰) were comparable, but did not reach the maximum (Figure 2). However, statistical analysis revealed no significant difference (p value = 0.91265) between the filtration rates in different salinities of the range [0‰ – 35‰.]

Nakwa (Closed) Lagoon

In the Nakwa Lagoon oysters, maximum filtration rates were reached in tanks of 100%, 80%, 60%, and 40% seawater (35.7‰, 29.0‰, 21.9‰, 14.4‰)(Figure 3). Rates at 20% seawater (8.4‰) were much lower, however similarly, statistical analysis revealed no significant difference (p value = 0.9965) between the filtration rates in different salinities of the range [0‰ – 36‰].

Comparative Mean Rates (Nakwa v. Benya)

Differences in the filtration rates of the two populations were significant (p<0.001)(Figure 4). Oysters gathered from Nakwa lagoon filtered at rates an average of 89% higher than their counterparts from Benya lagoon.

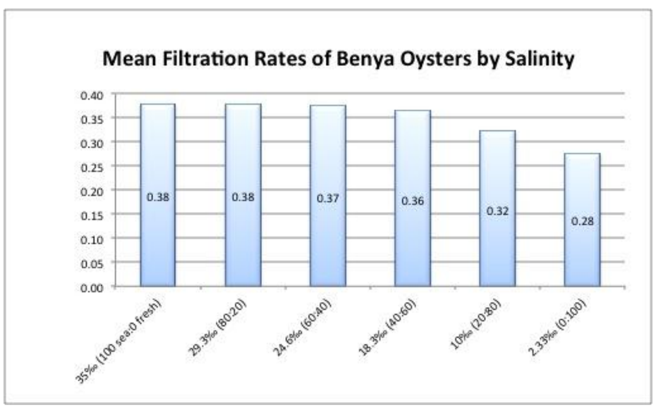

Figure 2. Mean Filtration Rates of Benya Oysters, By Salinit : depicts the mean filtration rates of the Benya oysters, grouped by the salinity of their experimental tanks. Include a slight interpretation for each of the graphs

DISCUSSION

The aim of this study was to build preliminary knowledge about the ecology of *C. tulipa*, as a step towards the development of an oyster fishery industry in Ghana. Differences found in the filtration behavior of two oyster populations indicate the possibility of two subspecies – one of which may be more suitable for future husbandry.

As previous research has theorized, a likely explanation for the disparity in filtration performance is the environmental differences of the source lagoons. The salinity range within which Nakwa oysters expressed their maximum filtration rates (~0 – 22‰) was almost twice that of Benya oysters (~0 - 9‰); the mean filtration rates of Nakwa oysters (6.567 ppm/min) were also significantly (p = 0.0002) higher than Benya oysters (3.485 ppm/min).Based on these results, it appears that oysters gathered from Benya, an open lagoon, were not as well adapted to fluctuation in the salinity of their environment, and therefore filtered less effectively when exposed to variable conditions. Oysters gathered from Nakwa were better adapted to fluctuation in salinity, perhaps because of their closed lagoon environment, and were able to filter more effectively across a broad range of salinities. This finding supports our original hypothesis: that the lagoon type from which oysters are sourced influences their filtration capacity, and therefore lagoon type should inform decisions about harvesting and cultivation sites.

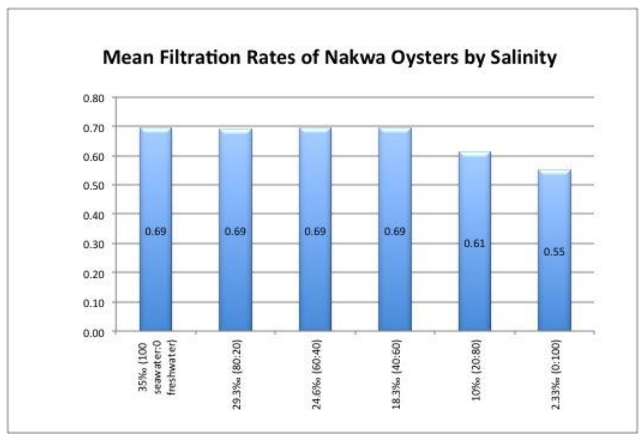

Figure 3. Mean Filtration Rates of Nakwa Oysters, By Salinity :the mean filtration rates of the Nakwa oysters, grouped by the salinity of their experimental tanks.

Although we have attributed the differences in filtration capacity to adaptation to the environment, it is also possible that the differences are genetic. The Nakwa and Benya oysters may, in fact, represent two distinct subpopulations within *C. tulipa*. Further research must be done in order to fully explore this possibility; the question would probably be best answered by a translocation experiment, in which oysters are removed as immature spat from their native lagoon environment, replaced in a lagoon of the opposite type, and removed as adults to have their filtration efficiency studied. Care should be taken, in the conduction of such an experiment, to ensure that genetic contamination does not occur; laboratory or artificial lagoons could initially be used as experimental lagoons. This would provide a simple and elegant experiment with which to begin exploring the relationship between genetics and environment in determining the filtration capacity of the West African mangrove oyster.

Due to factors beyond our control, there existed certain inconsistencies in our study that may have limited the accuracy of our results, and that may be improved in future repetitions. First, oysters were not collected from the two lagoons at exactly the same time daily. This was due to logistic constraints; one lagoon was more distant, and tidal fluctuations in the other limited collection time. Additionally, oysters from Nakwa Lagoon were collected as one single batch, whereas the initial group of Benya Lagoon oysters suffered high mortality in-lab, and therefore were largely replaced by oysters from a second collection group, making them a mixed batch. Last, control setups were disturbed in-lab, making controls inaccurate. If these issues could be resolved, the accuracy of results for future studies could be improved.

However, from this preliminary study of filtration rates, we can recommend that future development of an oyster fishery in Ghana should pursue one of two routes: if further work establishes that genetics are the major determinant of filtration capacity, spat collection should focus on closed lagoon oysters; alternately, if further work establishes that environment is the major determinant of filtration capacity, then fishery sites should be established in conditions mimicking the variable salinity of a closed lagoon environment. The oysters subsequently produced should be able to operate more effectively in a variety of conditions, and should therefore have higher yields and be less susceptible to environmental disturbances. It should also be noted that researchers found the shells of oysters from the closed lagoon smoother and easier to handle than those of the open lagoon oysters; this may be a benefit in fishery work.

In order to explore any of these possibilities, however, further information must be gathered about these organisms: *C. tulipa* must be subjected to further research on its genetics and metabolic physiology, as well as the best practices for sustainable, productive husbandry. Therefore, we highly recommended that additional inquiry into the viability of *C. tulipa* as a fishery oyster is carried out in Ghana, and that researchers subsequently explore the possibility of developing a mangrove oyster fishery in this and other countries.

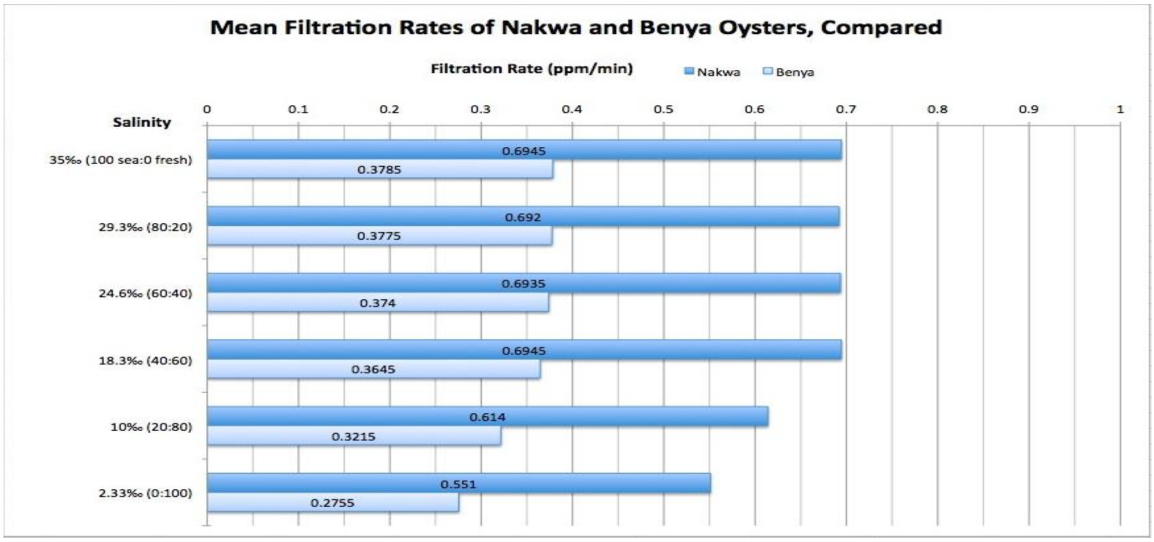

Figure 4. Comparative Mean Filtration Rates of Benya (Open) and Nakwa (Closed) Lagoon Oysters in All Salinities: compares the mean filtration rates of the Benya and Nakwa oysters, grouped by the salinity of their experimental tanks.

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