

Evaluation of Fecundity in Open Field Ponds and Polythene-Covered Ponds of *Oreochromis aureus* and *Oreochromis niloticus* in the Kenyan Highlands during the Warm Months from September to December

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Abstract

The major objective of the study was to evaluate the fecundity of *Oreochromis aureus* and *Oreochromis niloticus* reared in open field ponds and polythene-covered ponds in the Kenyan Highlands during the warm months (September to December). The study investigated the importance of different bio-systematic pond environments on the fish fecundity, while taking into account temperature variations and other pond bio-physio-chemical parameters. Fish were stocked in hapas within a polythene-covered ponds (PCP) and in open field ponds (OFP). Data was collected for fingerling production, monthly fecundity percentages, and correlation coefficients between fecundity and various bio-physio-chemical parameters (pH, conductivity, temperature, dissolved oxygen, atmospheric pressure, pond water pressure and midnight temperature). The study indicated significant variations in fingerling production across months, environments, and species. Correlation analysis between fecundity and pond parameters, temperature and dissolved oxygen was found to have major impact. Polythene-covered ponds showed higher fingerling production compared to open field ponds, suggesting a potential benefit of this practice.

O. aureus generally showed higher fecundity than *O. niloticus*. This study contributes valuable information for increasing tilapia breeding practices and enhancing aquaculture production in the Kenyan Highlands.

Keywords

Oreochromis aureus, *Oreochromis niloticus*, Fecundity, Pond Environment, Polythene Cover

1. Introduction

The growth of aquaculture is a major contributor to global food security in developing countries by being a major source of protein and a source of income for local communities [1]. *Oreochromis aureus* and *Oreochromis niloticus*, are the main reared species due to their rapid growth rates, adaptability to a variety of environmental conditions, and consistent high market demand [2]. Fecundity is the number of fries produced by a brooder per breeding cycle which varies in various environmental conditions and also the production systems applied [3]. It also plays a role in optimizing the breeding strategies and enhancing overall aquacultural productivity of the enterprise [4]. This hence makes fecundity a determining factor in the selection potential and population dynamics of fish species and also assists in maximizing sustainable fisheries and ethical aquaculture practices [5]. Therefore, to study fecundity based on either monthly breeding cycles or seasonally based cycles is not only important to the farm but also ethical, because it does not waste the brooders nor make the enterprise to invest when there are no fingerlings expected [6]. The biophysiochemical parameters that play a role in fecundity can intertwingle, confound and be multifaceted. This can lead to a need of very complex model to accommodate all of them with a lot of nesting involved or a lot of multicollinearities. In aquaculture biosystems, the management and manipulation of the biophysical factors plays a pivotal role on fecundity and the general production, efficacy and efficiency. In Kenyan Highlands, where tilapia farming is not widely practiced, seasonal fluctuations can imperatively affect fish reproduction and fecundity dynamics [7]. The warm months from September to December are characterized by elevated temperatures and high rainfall as shown in **Table 1** give favorable environmental conditions that promote tilapia breeding. Nonetheless, it is crucial to explore how various pond management practices affect fecundity during this peak breeding season to enhance production outcomes [8]. Polythene covered ponds [9], particularly those made of polythene local materials, are commonly used in many developing countries where real greenhouses cannot be constructed due to cost. Polythene covered ponds (PCP) do not have humidity control mechanisms or temperature, and are just constructed locally to change environment and enhance fish production through trying to manipulate the external environmental factors [10]. Polythene covered ponds serve multivar-

iate purpose, including increasing water temperature, minimizing water evaporation, and potentially influencing other important water quality parameters, such as dissolved oxygen levels and pH [11]. This study tries to exploit the polythene covered pond in both Nile tilapia and blue tilapia so that the cost of producing fingerlings does not necessarily have to rely on expensively constructed greenhouses [12] [13].

2. Materials and Methods

2.1. Experimental Location

This experiment was set up at Egerton University, Njoro campus, about 20 km from Nakuru town in Kenya. The *University main campus* lies at *coordinates* 0°22'11.0"S and 35°55'58.0"E (*Longitude*: 35.932779; *Latitude*: 0.369734). The University is 2,238 meters above sea level (7,324 feet). This makes it a high-altitude area. It is in ecological 3 and the environmental data obtained from Kenya Agricultural and Livestock Research Organization Njoro Centre indicates the temperatures have been very low for the last ten years.

2.2. Experimental Setup

The ponds were housed within a polythene covered pond (PCP) and in the open field ponds (OFP). Polythene covered ponds were being tried as a way to grow fish in a controlled environment while also benefiting from the natural light and warmth. Eight (four polythene covered and four open field ponds) identical concrete ponds per species, measuring 12 × 9 m were established for Nile and blue tilapia. Two brooders and one sire of a specific species were placed in a hapa of 1 m³ for three months. The PCP had eight hapas and OFP had eight hapas. This made a total of eight brooders of aureus in the PCP and eight brooders of niloticus in PCP. This was repeated in the OFP. Every hapa had a sire of the same species both in PCP and OFP as shown below in **Figure 1**.

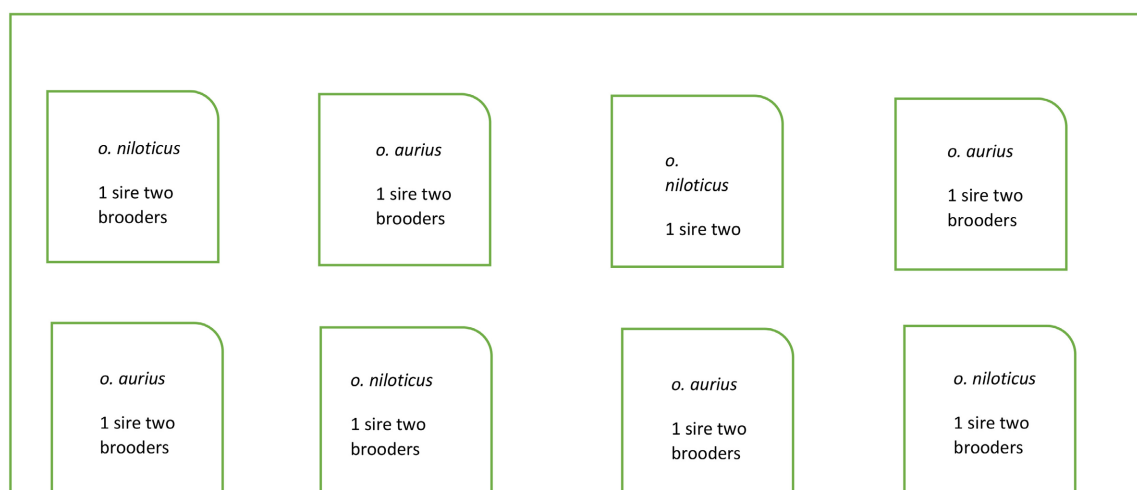


Figure 1. Pond layout both in polythene covered pond and open field pond.

Table 1. Njoro rainfall patterns in the months of September, October, November and December year 2020 obtained from Kenya Agricultural Research and Livestock Organization.

Year	Month	Max temp	Min temp	Mean temp	Total rainfall	No of days rained	Mean rainfall
2020	Sep	22	8	15	90.3	9	10.03
	Oct	22	10	11	130.9	12	10.91
	Nov	23	11	17	125	15	8.3
	Dec	25	9	17	5.4	3	1.8

2.3. Model for Data Analysis

The linear mixed model below was used to study the fecundity

Data analysis:

$$\begin{aligned}
 Y = & \alpha + \{\beta_1(\Delta pH)\} + \{\gamma_2(\Delta Cond)\} + \{\delta_3(\Delta Temp)\} + \{\varepsilon_4(\Delta DO)\} \\
 & + \{\zeta_5(AP)\} + \{\eta_6(WP)\} + \{\theta_7(MT)\} + \{\iota_8(TR)\} + \{\kappa_9(Cover)\} \\
 & + \{\lambda_{10}(Species)\} + \{\mu_{11}(\Delta pH(Cover))\} + \{\nu_{12}(\Delta pH(Species))\} \\
 & + \{\xi_{13}(\Delta Cond(Cover))\} + \{\omicron_{14}(\Delta Cond(Species))\} \\
 & + \{\pi_{15}(\Delta Temp(Cover))\} + \{\rho_{16}(\Delta Temp(Species))\} \\
 & + \{\sigma_{17}(\Delta DO(Cover))\} + \{\tau_{18}(\Delta DO(Species))\} \\
 & + \{\upsilon_{19}(AP(Cover))\} + \{\phi_{20}(AP(Species))\} \\
 & + \{\chi_{21}(WP(Cover))\} + \{\psi_{22}(WP(Species))\} \\
 & + \{\omega_{23}(MT(Cover))\} + \{\varrho_{24}(MT(Species))\} \\
 & + \{\aleph_{25}(TR(Cover))\} + \{\Upsilon_{26}(TR(Species))\}
 \end{aligned}$$

where: Y is the dependent variable, α is the intercept (baseline fecundity), $\beta_1(\Delta pH)$ ΔpH is the effect of the change in pH, $\gamma_2(\Delta Cond)$ is the effect of the change in conductivity, $\delta_3(\Delta Temp)$ is the effect of the change in temperature, $\varepsilon_4(\Delta DO)$ is the effect of the change in dissolved oxygen, $\zeta_5(AP)$ is the effect of atmospheric pressure, $\eta_6(WP)$ is the effect of pond water pressure, $\theta_7(MT)$ is the effect of midnight temperature, $\iota_8(TR)$ is the effect of temperature range, $\kappa_9(Cover)$ is the effect of pond cover type, $\lambda_{10}(Species)$ is the effect of fish species, $\mu_{11}(\Delta pH(Cover))$ is the interaction between change in pH and cover type, $\nu_{12}(\Delta pH(Species))$ is the interaction between change in pH and species, $\xi_{13}(\Delta Cond(Cover))$ is the interaction between change in conductivity and cover type, $\omicron_{14}(\Delta Cond(Species))$ is the interaction between change in conductivity and species, $\pi_{15}(\Delta Temp(Cover))$ is the interaction between change in temperature and cover type, $\rho_{16}(\Delta Temp(Species))$ is the interaction between change in temperature and species, $\sigma_{17}(\Delta DO(Cover))$ is the interaction between change in dissolved oxygen and cover type, $\tau_{18}(\Delta DO(Species))$ is the interaction between change in dissolved oxygen and species, $\upsilon_{19}(AP(Cover))$ is the interaction between atmospheric pressure and cover type, $\phi_{20}(AP(Species))$ is the interaction between atmospheric pressure and species, $\chi_{21}(WP(Cover))$ is the interaction between pond water pressure and cover type, $\psi_{22}(WP(Species))$ is the interaction between pond water pressure and species, $\omega_{23}(MT(Cover))$ is the interaction between midnight temperature and cover type, $\varrho_{24}(MT(Species))$ is the interaction between midnight temperature and species, $\aleph_{25}(TR(Cover))$ is the interaction between temperature range and cover type, $\Upsilon_{26}(TR(Species))$ is the interaction between temperature range and species.

is the interaction between pond water pressure and cover type, $\Psi_{22}(WP(Species))$ is the interaction between pond water pressure and species, $\omega_{23}(MT(Cover))$ is the interaction between midnight temperature and cover type, $\vartheta_{24}(MT(Species))$ is the interaction between midnight temperature and species, $\varkappa_{25}(TR(Cover))$ is the interaction between temperature range and cover type, $Y_{26}(TR(Species))$ is the interaction between temperature range and species, ε is the error term.

Table 2. Production of progeny fries.

ENVIRONMENT	SPECIES	MONTH	TOTAL PROGENY
OFP	<i>O. aureus</i>	SEP	200
		OCT	301
		NOV	170
		DEC	400
	<i>O. niloticus</i>	SEP	150
		OCT	251
		NOV	151
		DEC	242
PCP	<i>O. aureus</i>	SEP	130
		OCT	280
		NOV	165
		DEC	500
	<i>O. niloticus</i>	SEP	131
		OCT	202
		NOV	171
		DEC	105

Table 3. Monthly fecundity in percentage (2020).

MONTH	ENVIRONMENT	SPECIES	TOTAL No. OF FINGERLINGS	% Monthly	% Environment	% Species	Temp range °C
SEP	OFP	AUREUS	200	17.2	57	57	16
		NILOTICUS	150			43	
	PCP	AUREUS	130		49.8		
		NILOTICUS	131		51.1		
OCT	OFP	AUREUS	301	29.1	53.4	54.5	11
		NILOTICUS	251			45.5	
	PCP	AUREUS	280		58.1		
		NILOTICUS	202		41.9		
NOV	OFP	AUREUS	170	18.5	48	52.9	12

Continued

		NILOTICUS	151		47.1	
	PCP	AUREUS	165	52	49.1	
		NILOTICUS	171		50.9	
	OFP	AUREUS	400	51.5	63.3	
DEC		NILOTICUS	242	35.1	37.7	16
	PCP	AUREUS	500	48.5	82.6	
		NILOTICUS	105		17.4	
	TOTAL		3549			

Table 4. Total fingerlings by environment.

Environment	Total Fingerlings	% of Total
OFP	1564	44.1%
PCP	1985	55.9%

Table 5. Total fingerlings by month.

Month	Total Fingerlings	% of Total
September	611	17.2%
October	1134	31.9%
November	557	15.7%
December	1247	35.1%

Table 6. Total fingerlings by species.

Species	Total Fingerlings	% of Total
Aureus	2005	56.5%
Niloticus	1544	43.5%

Table 7. September 2020.

Species	Environment	Fingerlings
Aureus	OFP	200
Niloticus	OFP	150
Aureus	PCP	130
Niloticus	PCP	131

Table 8. October 2020.

Species	Environment	Fingerlings
Aureus	OFP	301
Niloticus	OFP	251

Continued

Aureus	PCP	280
Niloticus		202

Table 9. November 2020.

Species	Environment	Fingerlings
Aureus	OFP	170
Niloticus		151
Aureus	PCP	165
Niloticus		171

Table 10. December 2020.

Species	Environment	Fingerlings
Aureus	OFP	400
Niloticus		242
Aureus	PCP	500
Niloticus		105

2.4. Model for the Correlations of the Parameters

Multiple Linear Regression Model was used

$$\begin{aligned}
 Y = & \beta_0 + \{\beta_1(\Delta pH)\} + \{\beta_2(\Delta Temp)\} + \{\beta_3(\Delta Cond)\} + \{\beta_4(\Delta DO)\} \\
 & + \{\beta_5(AP)\} + \{\beta_6(WP)\} + \{\beta_7(MT)\} + \{\beta_8(TR)\} \\
 & + \{\beta_9 Cover\} + \{\beta_{10} Species\} + \varepsilon
 \end{aligned}$$

where:

Y is the dependent variable, representing the reproductive potential or egg production of the fish. It's what we are trying to predict or understand, β_0 is the intercept. It represents the baseline fecundity when all other variables are zero or at their reference levels. It's a constant in the model, $\beta_1(\Delta pH)$ is the effect of the change in pH (Morning pH - Evening pH) on fecundity. A positive β_1 means that a larger difference between morning and evening pH is associated with higher fecundity, while a negative β_1 suggests the opposite, $\beta_2(\Delta Temp)$ is the effect of the change in conductivity (Morning Conductivity - Evening Conductivity) on fecundity. A positive β_2 means that a larger difference between morning and evening conductivity is associated with higher fecundity, while a negative β_2 suggests the opposite, $\beta_3(\Delta Cond)$ is the effect of the change in temperature (Pond Temperature Morning - Pond Temperature Evening) on fecundity. A positive β_3 means that a larger difference between morning and evening pond temperature is associated with higher fecundity, and vice-versa, $\beta_4(\Delta DO)$ is the effect of the change in dissolved oxygen (Dissolved Oxygen Morning - Dissolved Oxygen Evening) on fecundity. A positive β_4 means that a larger difference between morning and even-

ing dissolved oxygen is associated with higher fecundity, and vice-versa, $\beta_5 (AP)$ is the effect of atmospheric pressure on fecundity, $\beta_6 (WP)$ is the effect of pond water pressure on fecundity, $\beta_7 (MT)$ is the effect of midnight temperature on fecundity, $\beta_8 (TR)$ is the effect of temperature range on fecundity, $\beta_9 Cover$ is the pond cover type (Open Pond or Polythene Cover). One category would be the reference (e.g., Open Pond). β_9 would then represent the difference in fecundity between the Polythene Cover and the Open Pond, $\beta_{10} Species$ is the fish species (Aureus or Niloticus). One species would be the reference. β_{10} would then represent the difference in fecundity between the other species and the reference species and ε is the error term. It represents the unexplained variation in fecundity, the part not accounted for by the other variables in the model [14]. It captures random fluctuations and other factors not included in the model [15].

Table 11. Correlation of pond parameters in the months of study of fecundity.

	MORN PH	EVEN PH	MORN COND	EVEN COND	POND TEMP MORN	POND TEMP EVEN	TOP POND TEMP MORN	TOP POND TEMP EVEN	DIS-SOLVED O ₂ MORN	DIS-SOLVED O ₂ EVEN	ATMOS PRESSURE (KPA)	POND WATER PRESS	MIDNIGHT TEMP
MORN PH	1												
EVEN PH	0.986513	1											
MORN COND	0.064637	0.002842	1										
EVEN COND	0.374746	0.421731	0.190066	1									
POND TEMP MORN	0.939638	0.926643	0.085893	0.314421	1								
POND TEMP EVEN	0.968702	0.956404	0.079515	0.354132	0.979471	1							
TOP POND TEMP MORN	0.934215	0.916754	0.089059	0.294784	0.995872	0.979847	1						
TOP POND TEMP EVEN	0.976202	0.968246	0.06779	0.374614	0.97411	0.996026	0.969748	1					
DISSOLVED O ₂ MORN	0.288633	0.229826	0.169546	-0.17568	0.526261	0.430973	0.562867	0.376919	1				
DISSOLVED O ₂ EVEN	0.515737	0.56076	-0.1268	0.422092	0.332731	0.444702	0.328133	0.480798	-0.2838	1			
ATMOS PRESSURE (KPA)	0.559365	0.556786	-0.02299	0.132683	0.631018	0.621405	0.634382	0.613209	0.377521	0.193556	1		
POND WATER PRESS	0.590652	0.590845	-0.03147	0.156291	0.654924	0.64977	0.657159	0.643502	0.362988	0.231286	0.998736	1	
MIDNIGHT TEMP	0.90618	0.878167	0.123396	0.253955	0.983246	0.97044	0.987836	0.958111	0.600692	0.259627	0.637722	0.657701	1

3. Discussion

Rainfall patterns for the four months of year 2020 as shown in **Table 1**, fish growth shows information for the four months (September, October, November, and December), two environments (Open field Pond and Polythene Cover), and two species (Aureus and Niloticus). Total Fish Count 3549 fish were recorded during the four months as shown in **Table 2** and **Table 3**. Environmental percentage shows

proportion of fish found in each environment where Polythene Cover environment has higher percentage of fish than open field environments as shown in **Table 4**. Monthly variation shows December having the highest total fish count (1247) October (1134), September (611), and November (657) as shown in **Table 5**. This concludes seasonal impacts on fish growth and recording. Species distribution shows aureus to have been produced more than Niloticus in the four months but degree of dominance varies [16]. Species percentage shows higher production of Aureus compared to Niloticus as shown in **Table 6** [17]. Environmental impact on Polythene Cover ponds has higher fish counts compared to the Open Pond, particularly on aureus species due to controlled and a favorable environment and controlled predation for growth [18]. Open Pond environment shows more fluctuation across the four months. This is due to greater exposure to external environmental changes like temperature and weather [19]. Aureus has higher numbers than Niloticus in both environments and across the four months. This indicates faster growth rate, better adaptation to the experimental conditions [20]. Niloticus have lower numbers though it contributes significantly to the total fish count. Monthly percentage shows contribution of each month to the total fish count where December shows high count while September has the lowest as shown in **Tables 7-10**. Temperature range suggests that temperature plays a big role in fish growth where October and November have lower temperature ranges with lower total fish counts [21]. December has higher temperature range thus having highest count. Morning pH shows a positive correlation with fecundity while Evening pH shows a negative correlation with fecundity thus using the difference (Morning pH - Evening pH) as a predictor in the model. Conductivity correlations are negative making a larger difference between morning and evening conductivity which makes lower fecundity [22]. Temperature effects are complex and vary across species, environment, and month. Dissolved Oxygen varies. Atmospheric and Pond Water Pressure shows positive correlations, suggesting a potential positive influence on fecundity. Midnight Temperature and Temperature Range show variable correlations as shown in **Table 11** [23]. Pond Cover type shows the difference in fecundity between open ponds and polythene-covered ponds. Fish Species quantify the difference in fecundity between the two fish species [24].

4. Conclusion

PCP are not green houses. They do not have humidity control, temperature control neither sensors for environmental changes. This makes them optimal for Africa where farmers cannot afford construction of greenhouses. This project is farmer-based bearing in mind what happens in the African continent where there is under development and lack of capital for infrastructure. The results obtained assist in alleviating the challenges of tilapia farming in the African Highlands [23] [24]. Data shows Polythene Cover environment shows higher fish counts compared to the Open field Pond making it have potential growth advantage. Aureus

are produced in high numbers compared to *Niloticus* suggesting better adaptation to the conditions. Temperature appears to play a role in fish growth [25]. The analysis shows the relationships between environmental factors and fish fecundity. Multiple linear regression model offers a better approach to analyzing these relationships. The reaction of parameters should be considered before elimination. Top Pond Temperature Morning and Evening show weak and inconsistent correlations with fecundity. They might be redundant if “Pond Temperature Morning” and “Pond Temperature Evening” are already in the model. Midnight Temperature is mostly weak and inconsistent. Temperature Range is weak. The importance of temperature range might be captured by the difference between morning and evening pond temperatures [26]. Parameters with Inconsistent Correlations (varying greatly by species, environment, or month) are dissolved Oxygen Morning and Evening. Its effect on fecundity might be complex and non-linear, or its influence might be mediated by other factors [27]. Parameters with Moderate to High Correlations is Pond Water Pressure. Important Considerations before Eliminating Variables are Biological Significance where a low correlation has biological relevance [28]. Collinearity can lower the standard errors of the regression coefficients and make it difficult to determine the individual effects of each variable [29]. Variance Inflation Factor (VIF) can help detect multicollinearity. Interaction effects show the individual relationships between each predictor and fecundity model [30].

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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